Mu2e Accelerator and Proton Beam Update

- *Outline:*
  - *Overview / Operating Scenario*
  - *Extraction / Extinction*
  - *Beam Line / Target / Absorber*
  - *Recent Participation, Efforts*

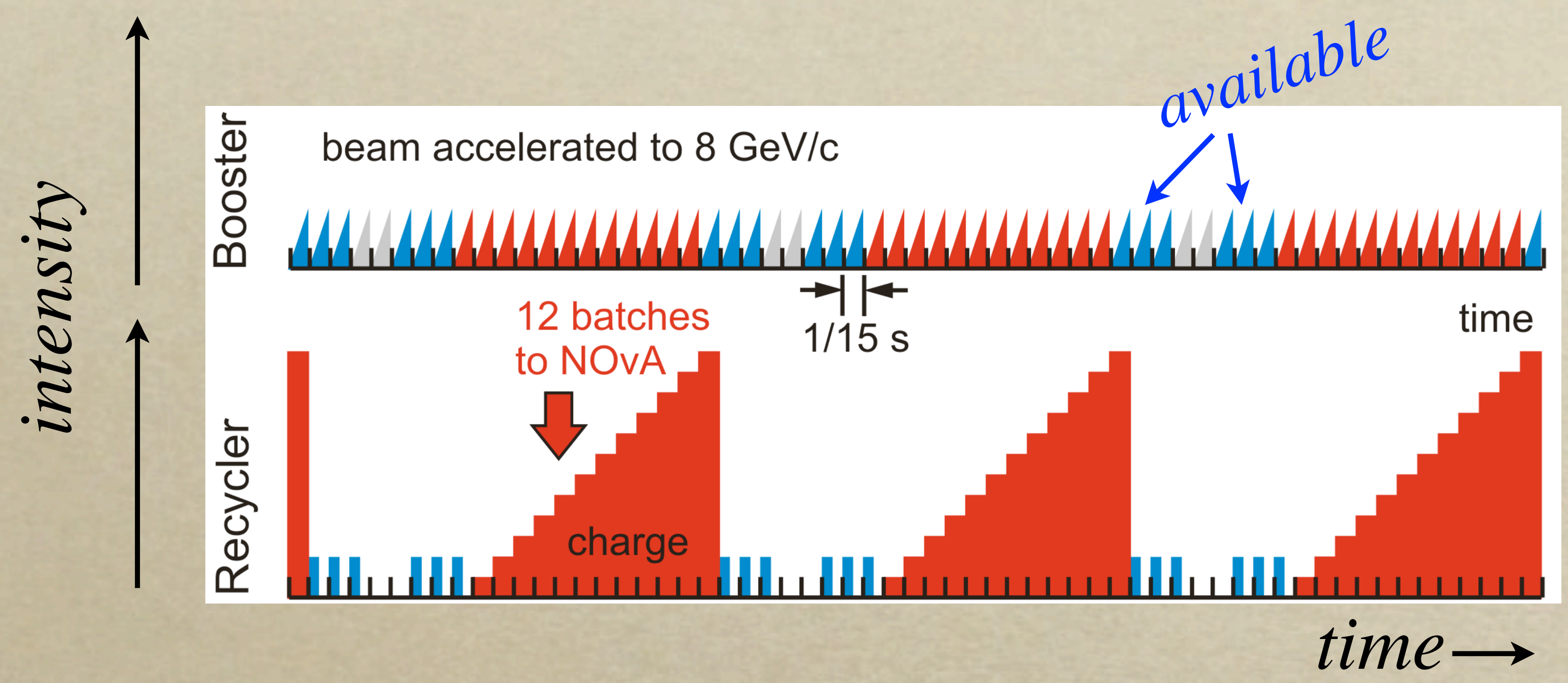
Mike Syphers

L2/Accelerator Assoc. PM

Very Brief Review

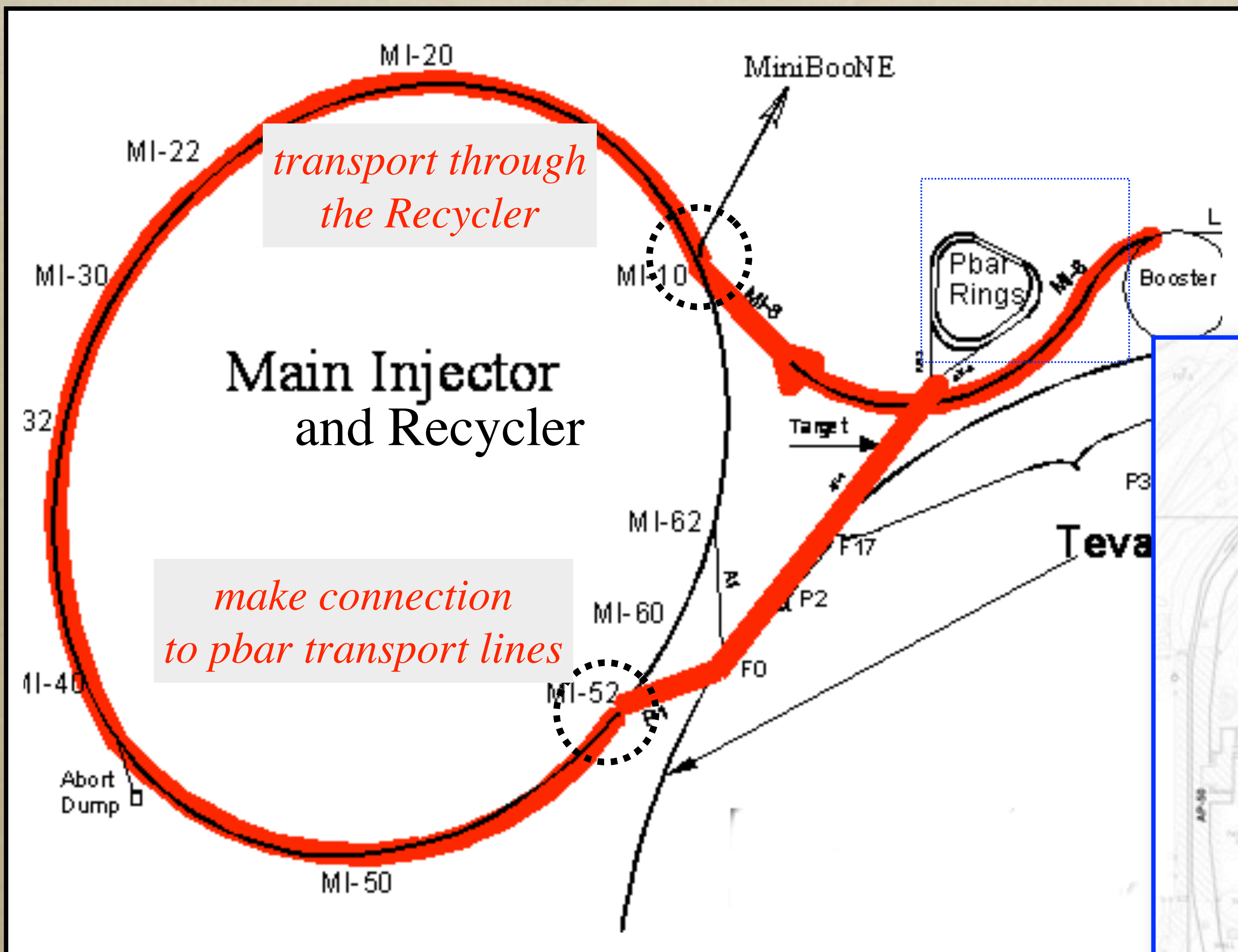
NuMI/NOvA, after Run II

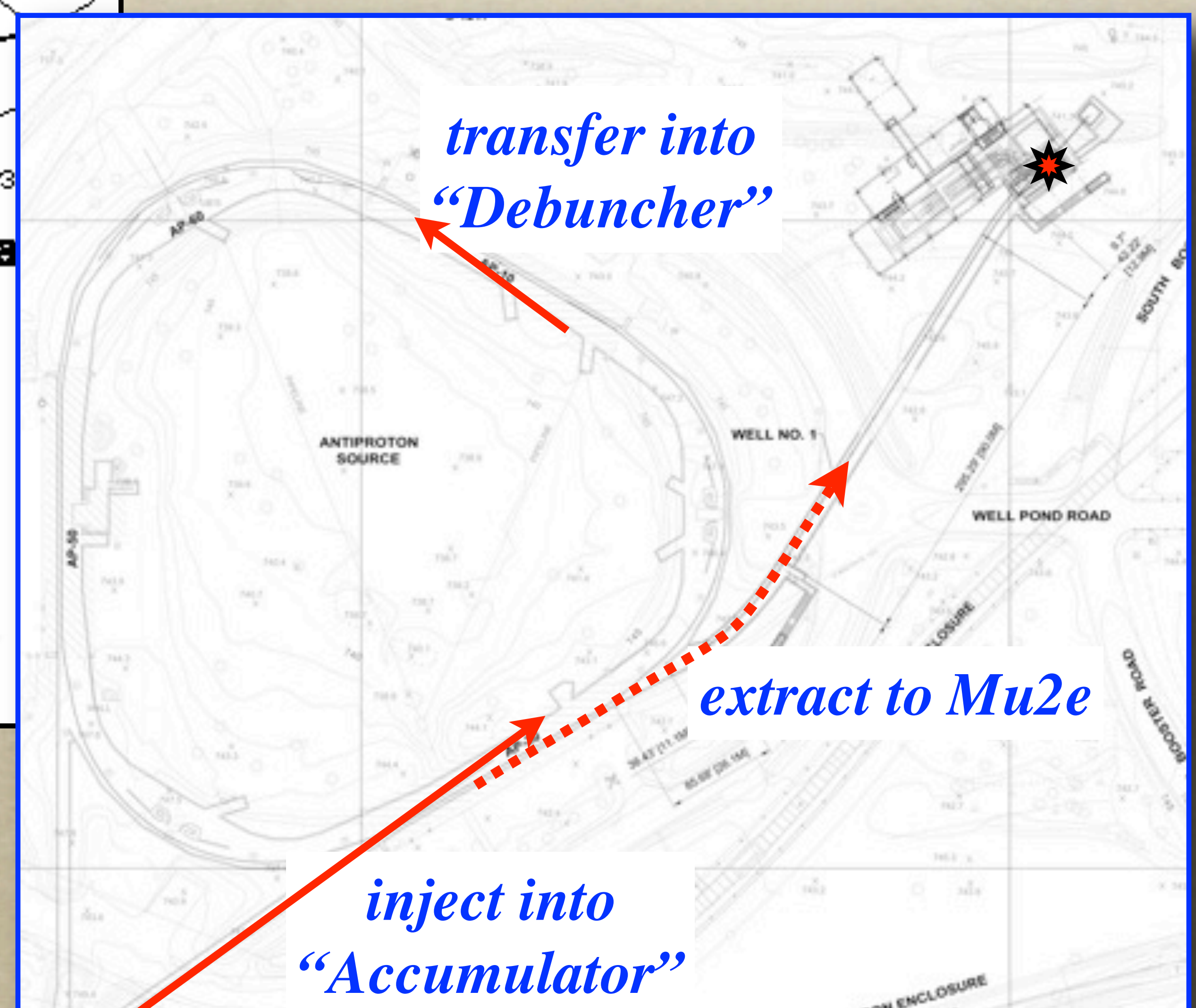
- *Following Run II, the NOvA experiment will ultimately use up to 12 Booster cycles per MI cycle*



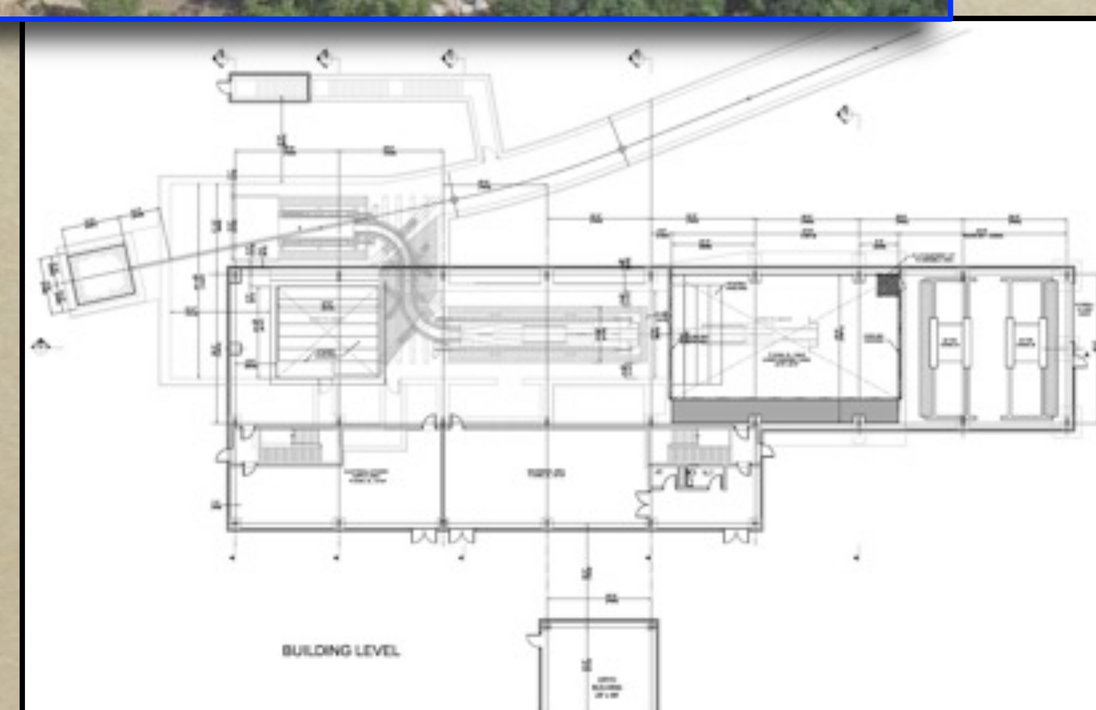
- *20 15-Hz Booster cycles (1.333 sec) per NOvA cycle*

Beam Transport from Booster



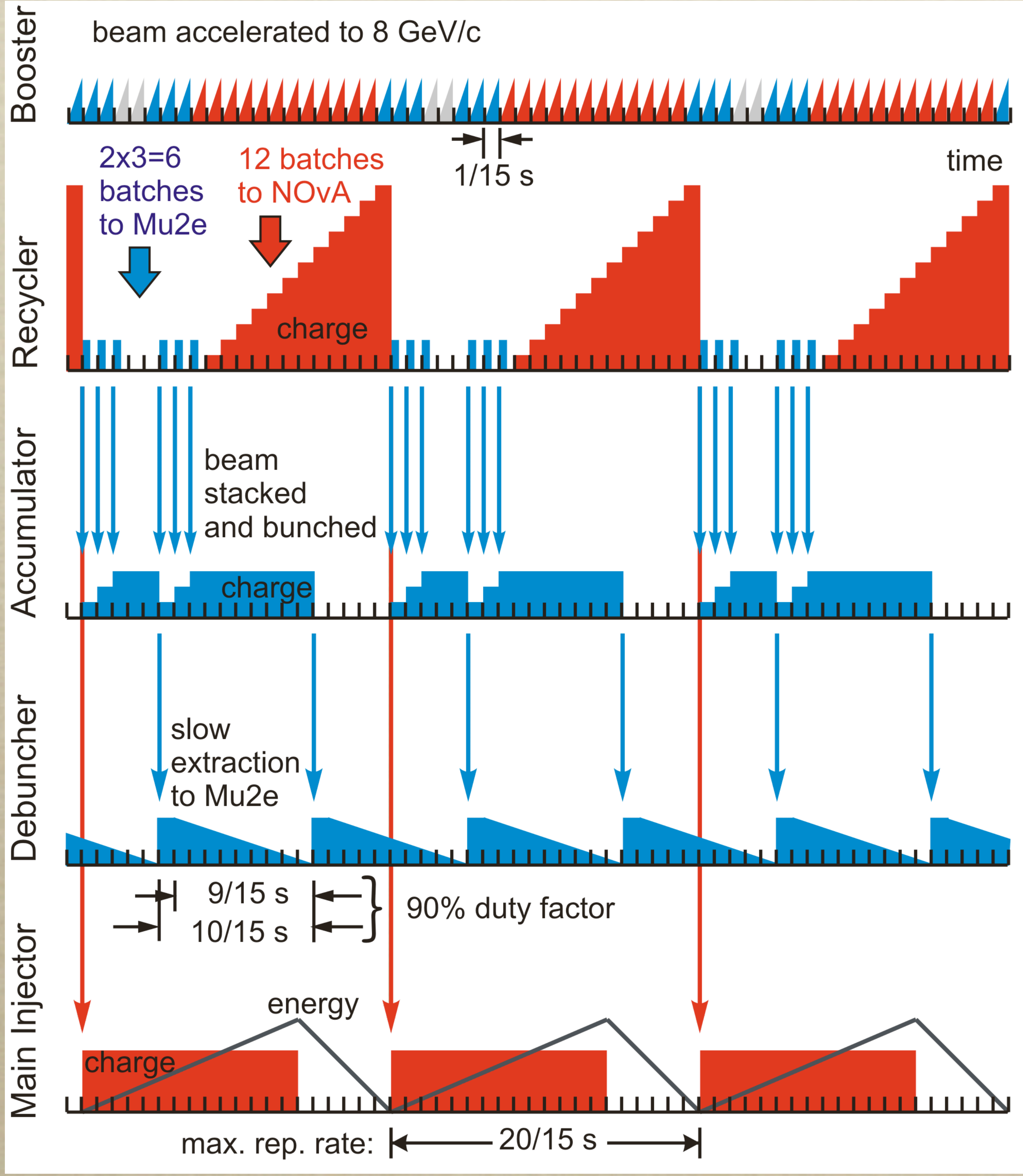


Experiment Location



Baseline Operating Scenario

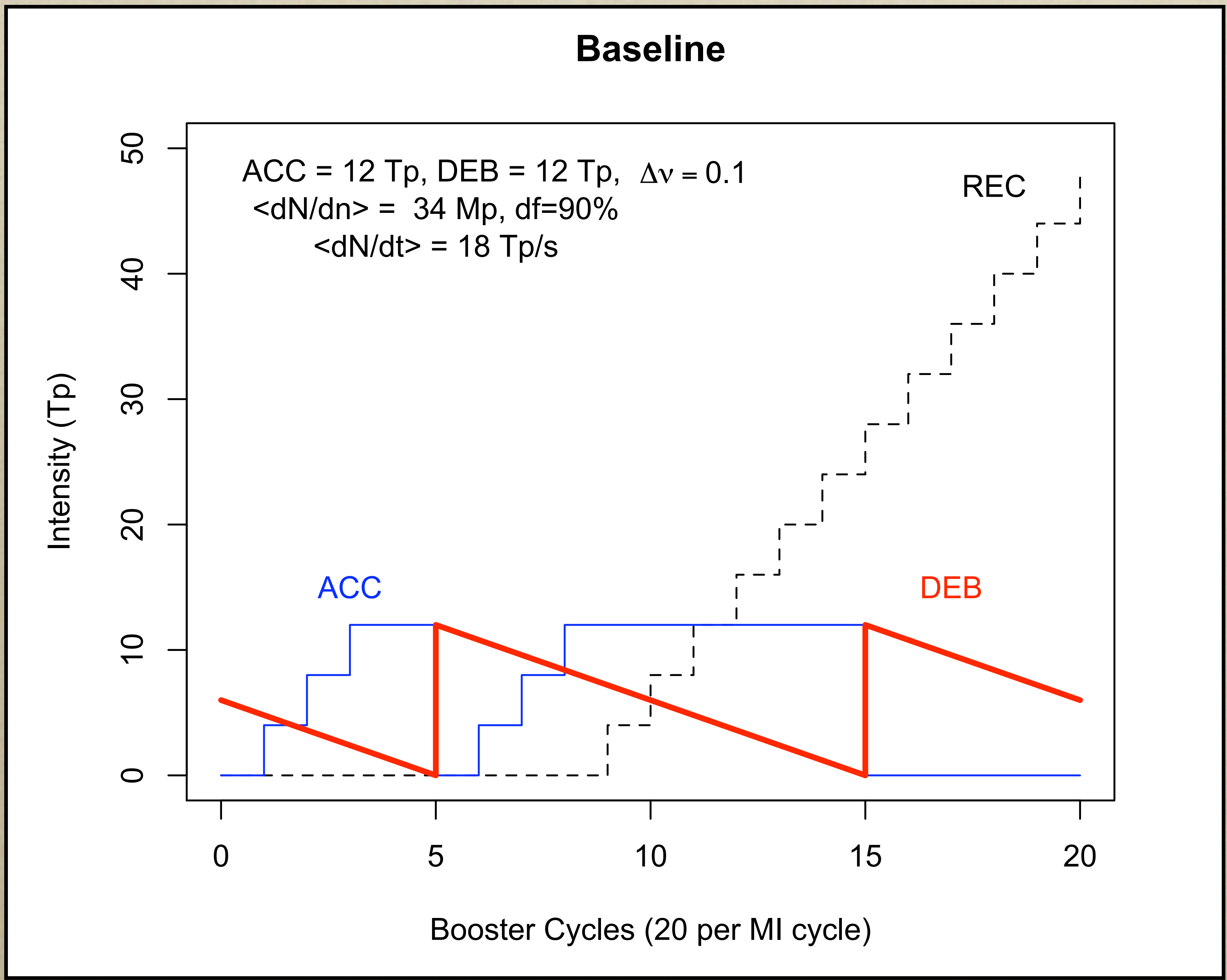
- *Inject/stack beam into Accumulator, form single bunch, and transfer to Debuncher for slow spill*
- *In principle, w/ $4x10^{12}$ (4 Tp) per Booster batch, Mu2e receives 18 Tp/s on target, $1.8x10^{20}$ in 10^7 s.*
- *15 Hz Booster assumed*
- *Does not affect NOvA operation*
- *Will require improved safety mitigation for "pbar" rings*



Mu2e Baseline Beam Proposal

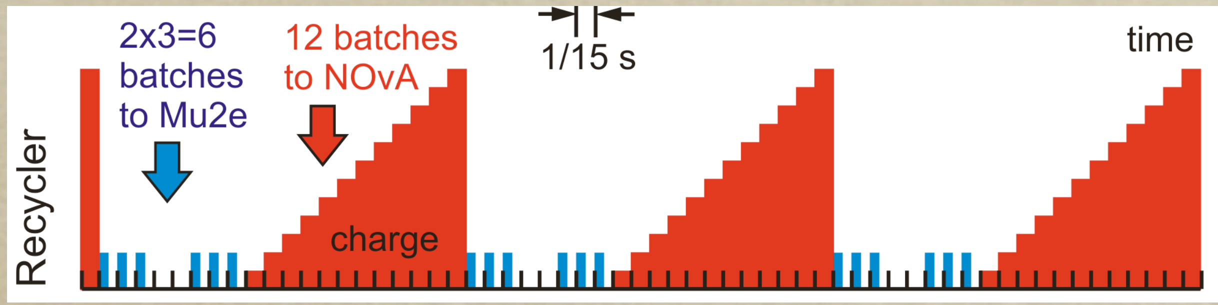
- *Experiment "cycle" time of 667 ms*
  - *3 Booster batches fed into Accumulator ring*
    - *form single bunch -- 1.2 x 10^{13} (!!)*
  - *transfer bunch into Debuncher ring; phase rotate to form ~30-40 ns (rms) bunch; slow extract*
- *Repeat twice during single 1.333 s NOvA cycle*
  - *NOvA uses 12/20*15 Hz cycles = 9 Hz*
  - *Mu2e would use 6/20*15 Hz cycles = 4.5 Hz*
    - *Note: 18×10^{12} p/sec (18 Tp/s) on average (25.7 kW @ 8.9 GeV)*

Proposal's Scenario



New Scenario: Threading through NOvA

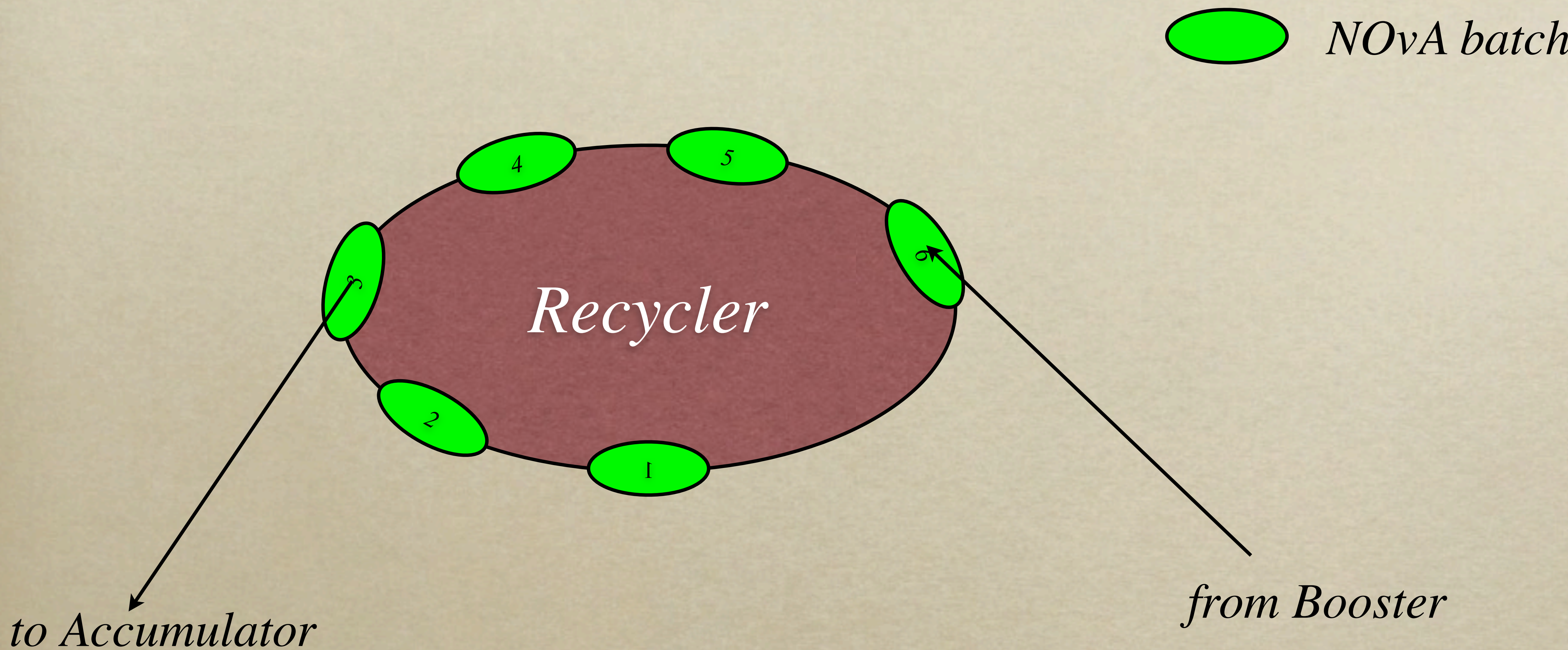
- *Want to lower the instantaneous intensity, but keep a relatively constant rate to the experiment*
- *Scenarios had been constrained by the times at which Booster cycles are available for Mu2e -- want ~3 in a row, equally spaced*



- *Loosen the constraint by allowing beam to "thread" in-and-out through the Recycler's injection gap while beam is circulating that is destined for NOvA**

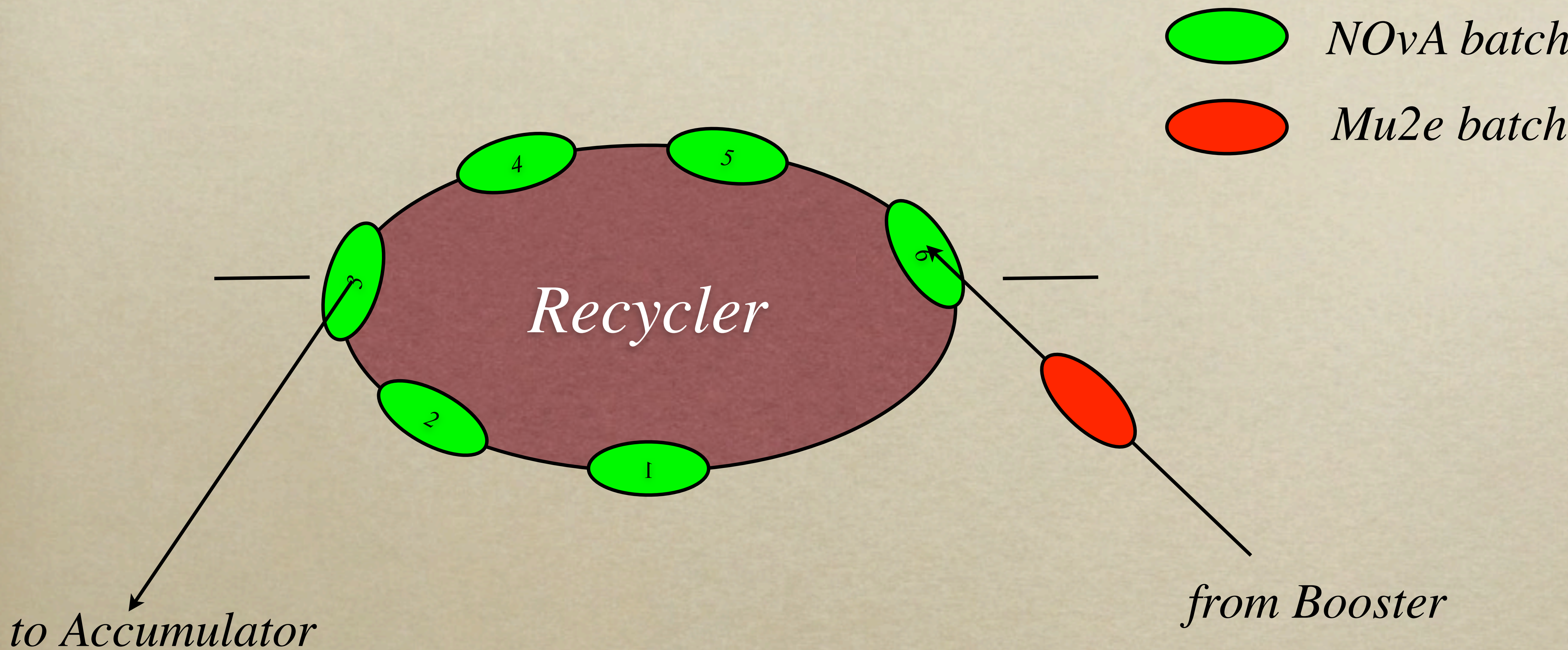
**Original suggestion made by some linear combination of C. Ankenbrandt and M. Popovic*

Threading Mu2e through NOvA



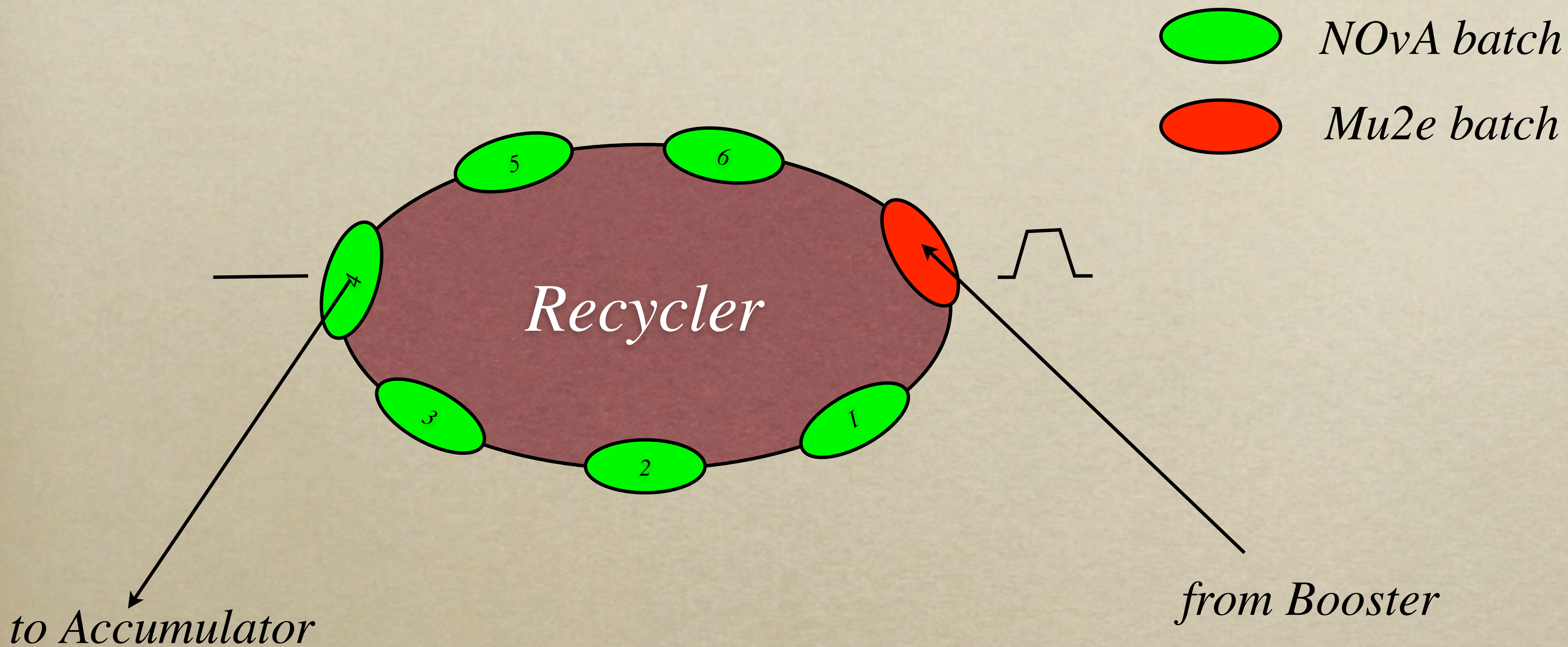
- *Recycler circumference is 7× the Booster*
- *NOvA accepts 6 "batches" from Booster, then performs "slip stacking" to a slightly different energy (and hence different orbit) in order to accept 6 more*
- *Use the existing "gap" to thread beam through toward Mu2e*

Threading Mu2e through NOvA

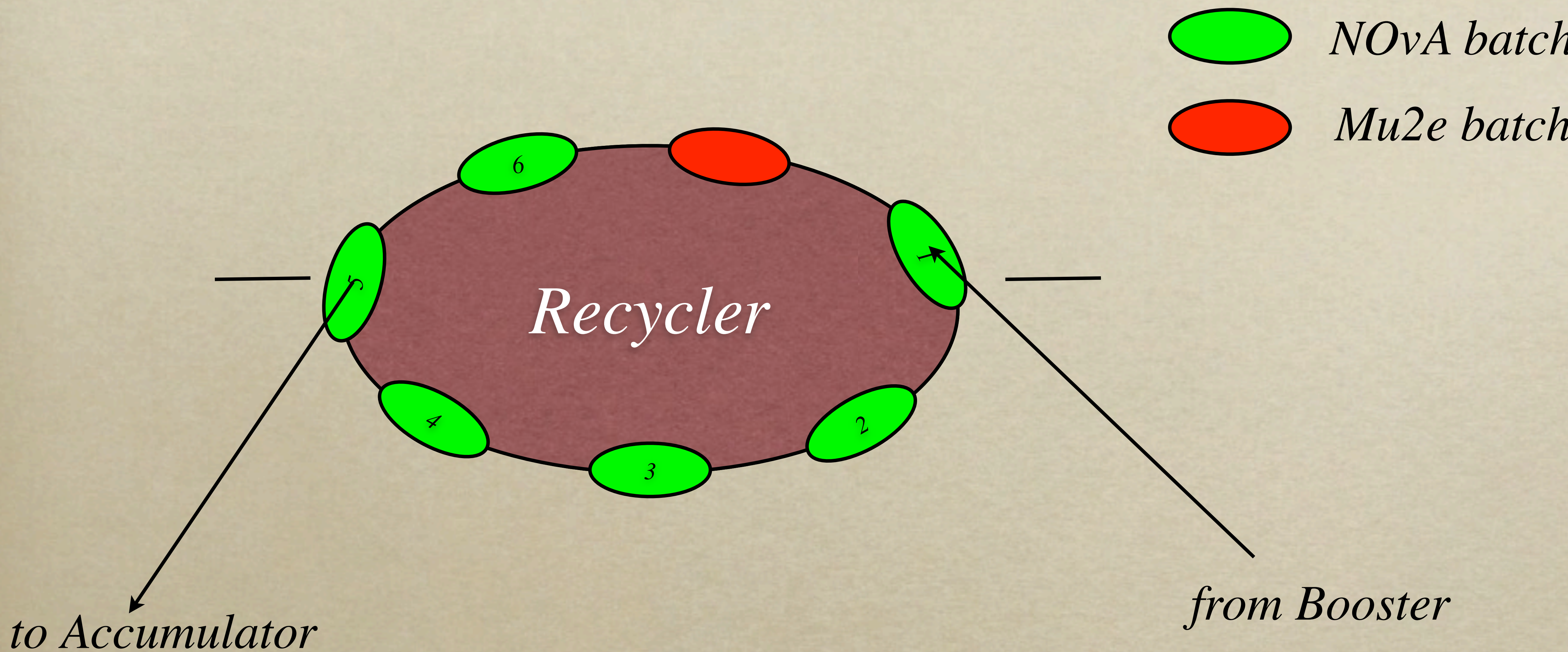


Collaboration Meeting 3 Jun 2010

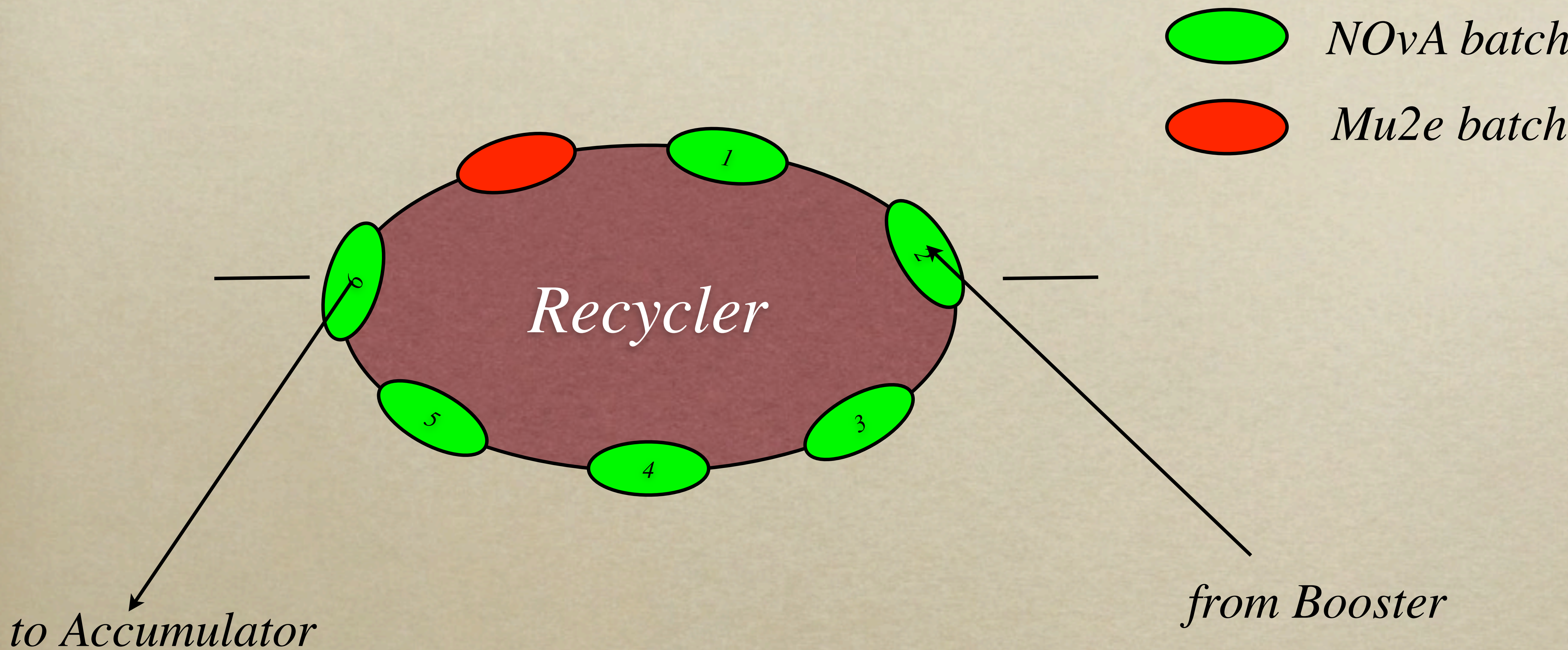
Threading Mu2e through NOvA



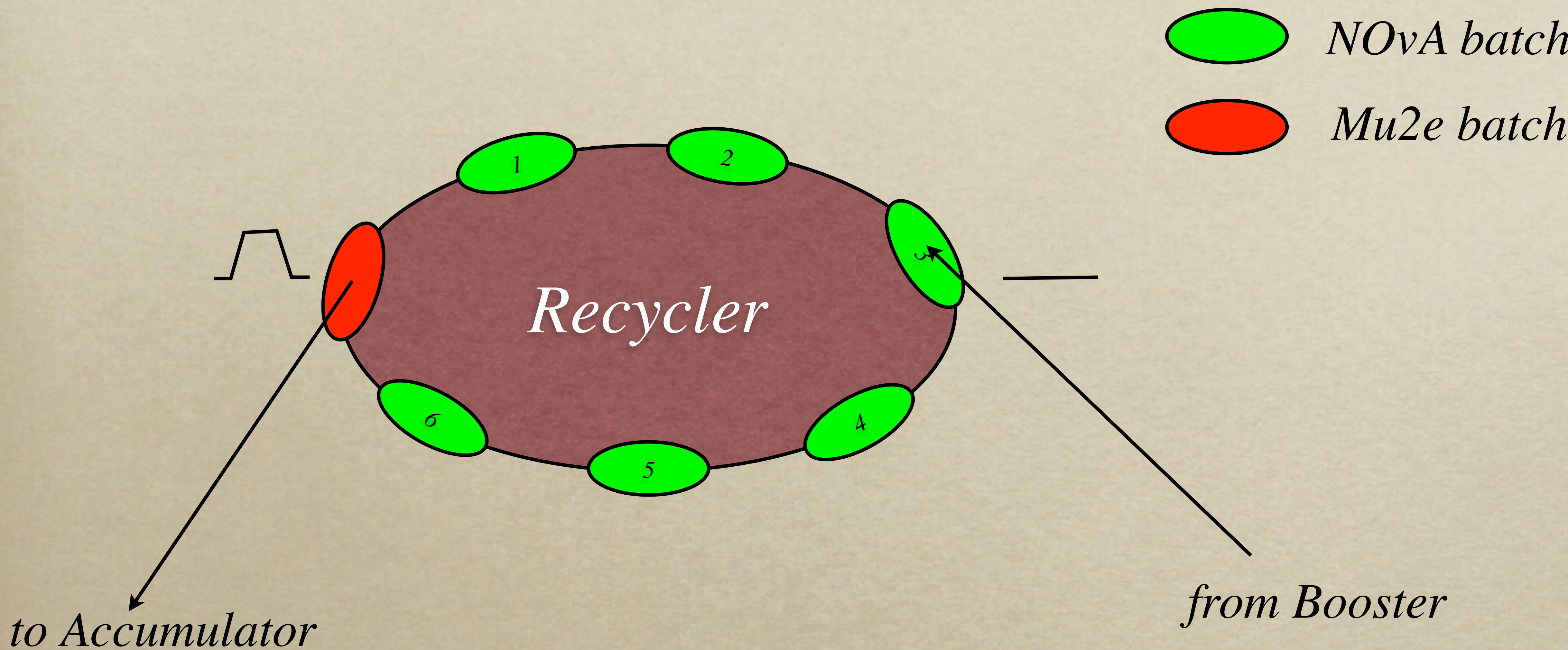
Threading Mu2e through NOvA



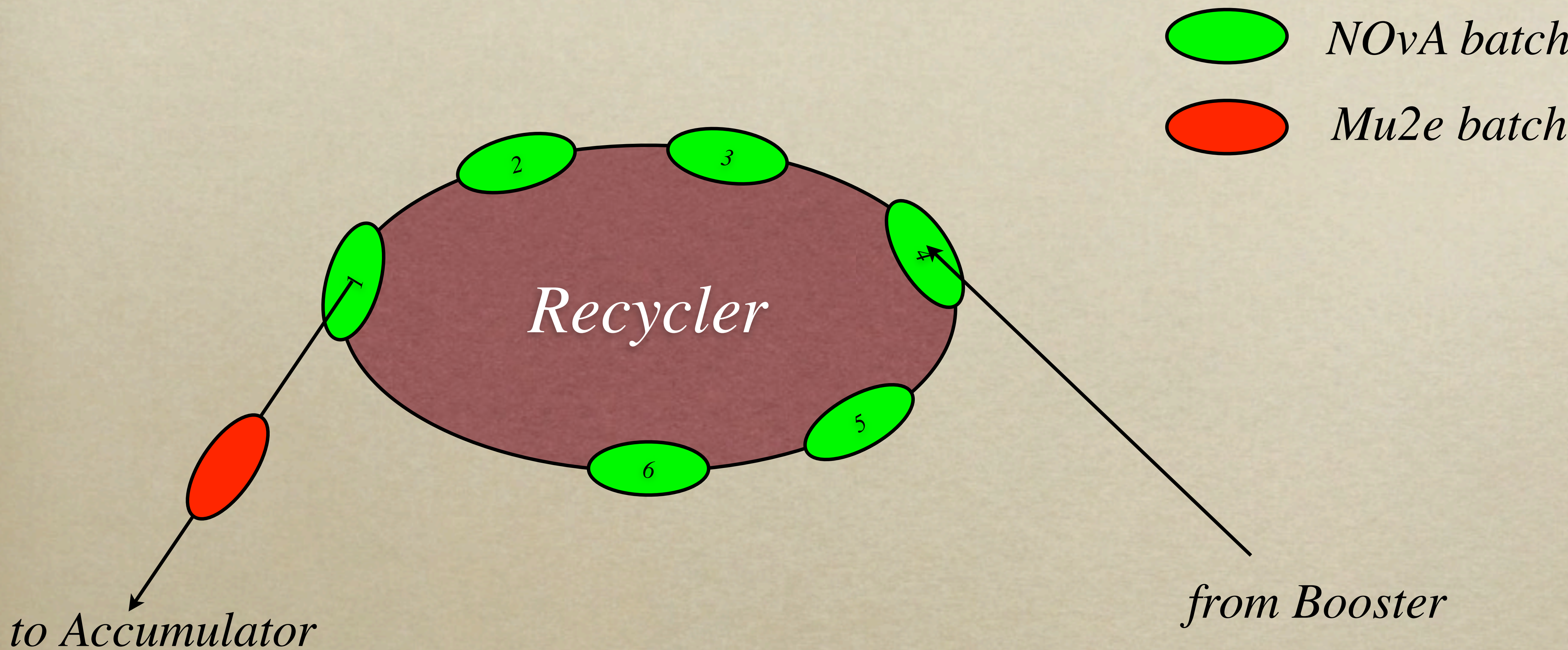
Threading Mu2e through NOvA



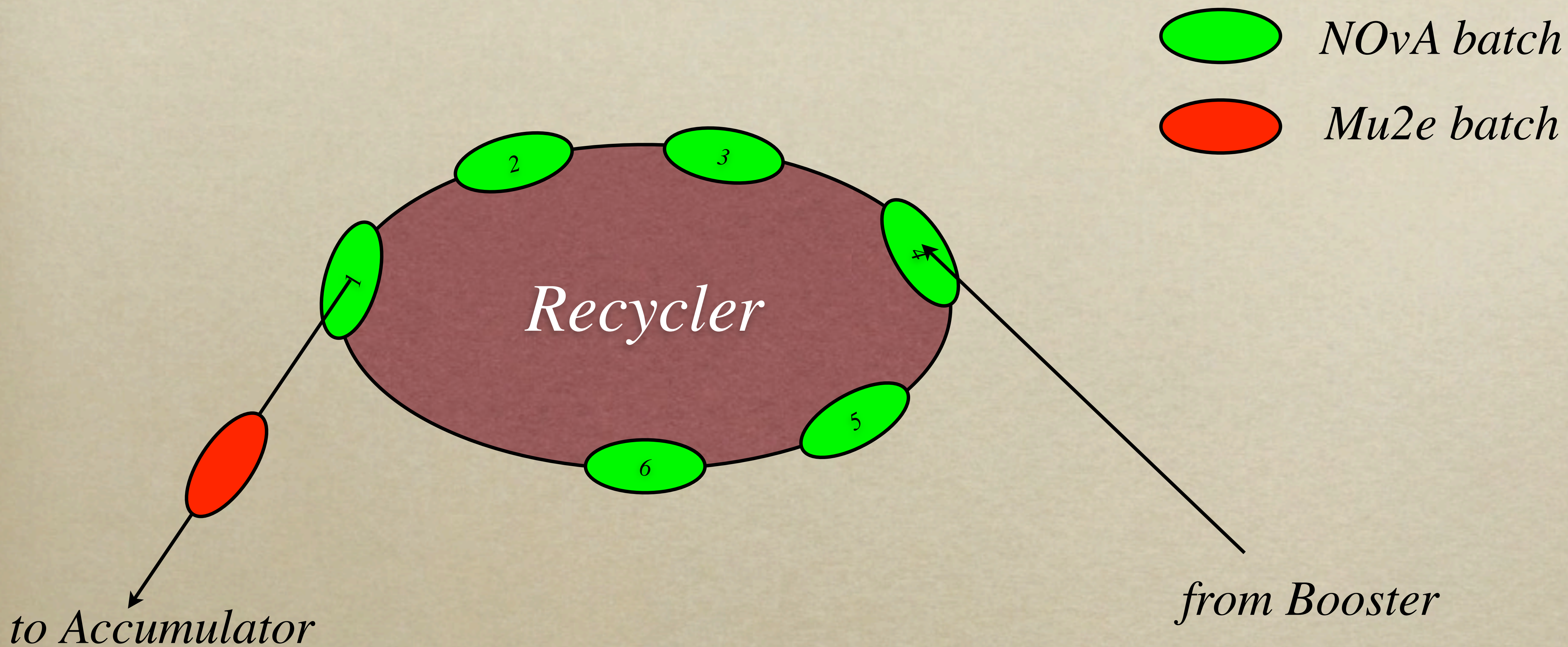
Threading Mu2e through NOvA



Threading Mu2e through NOvA

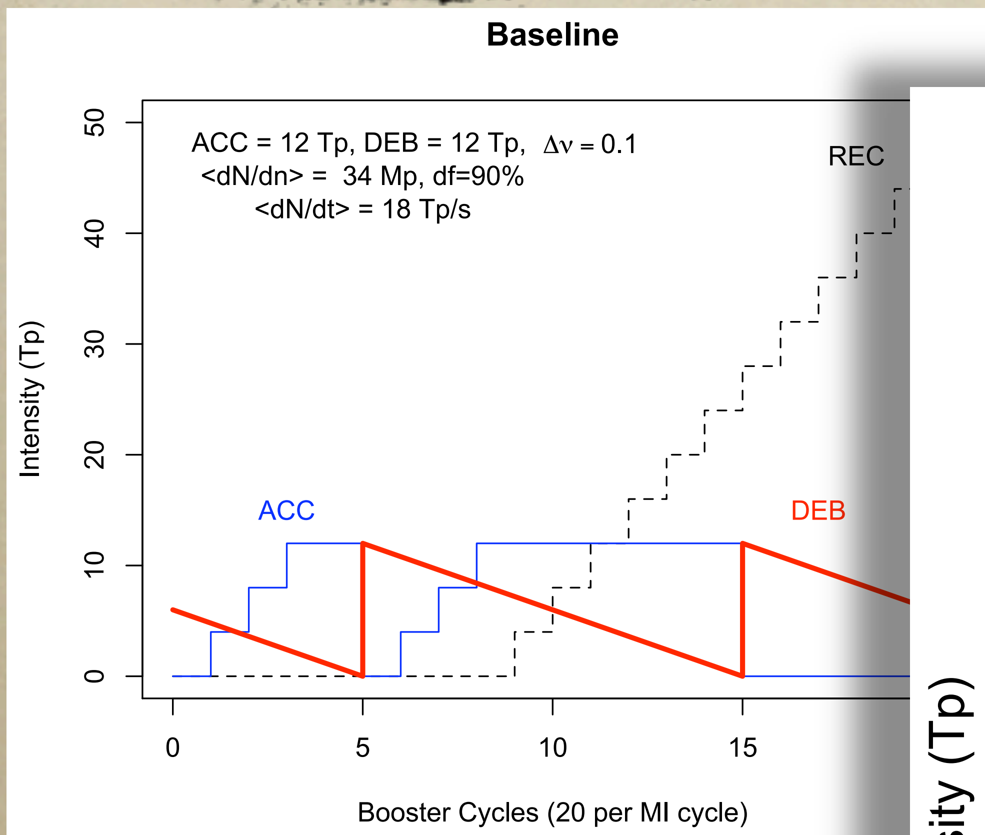


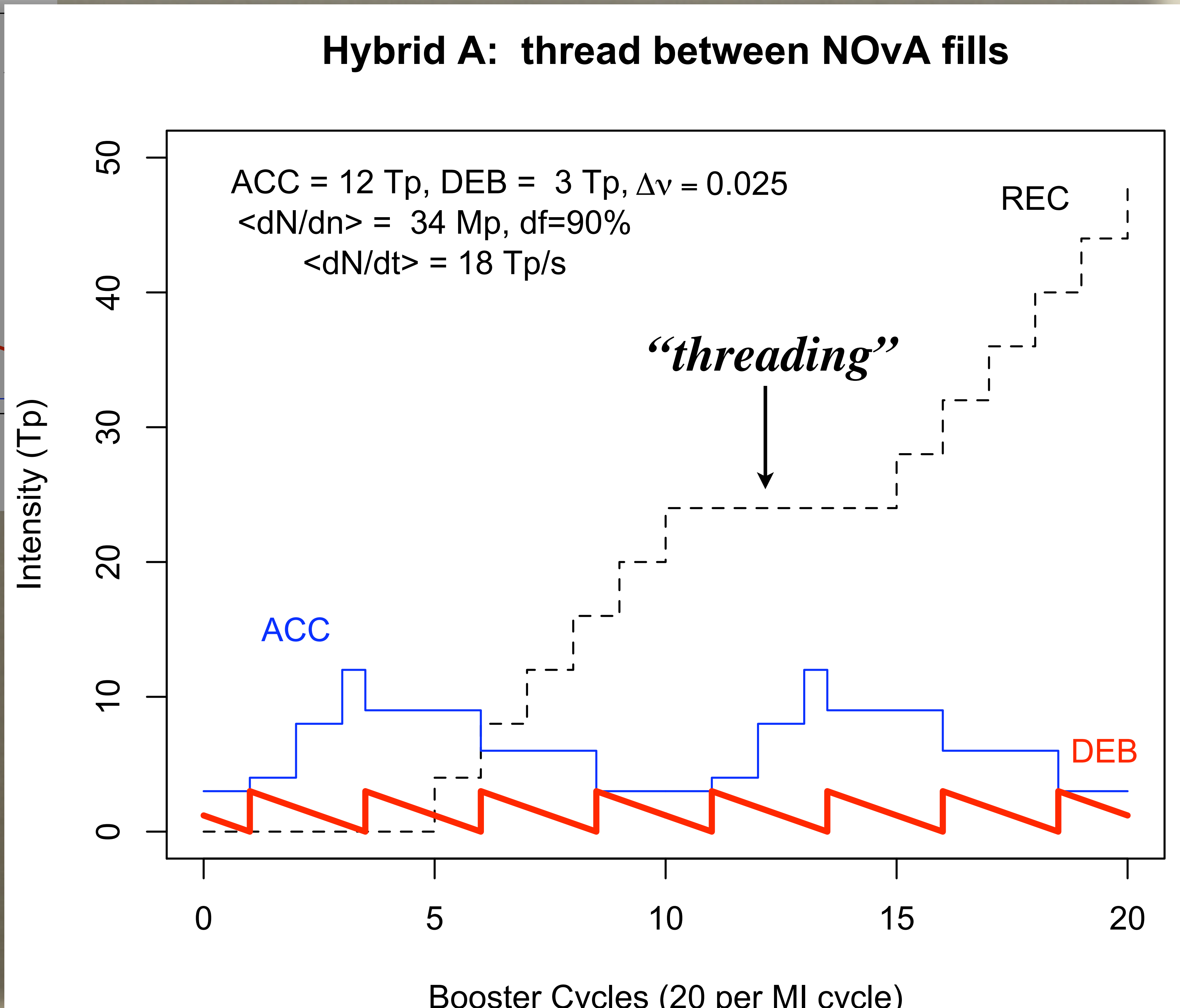
Threading Mu2e through NOvA



After final batches toward Mu2e have passed through, inject the last six batches for NOvA

Threading through NOvA

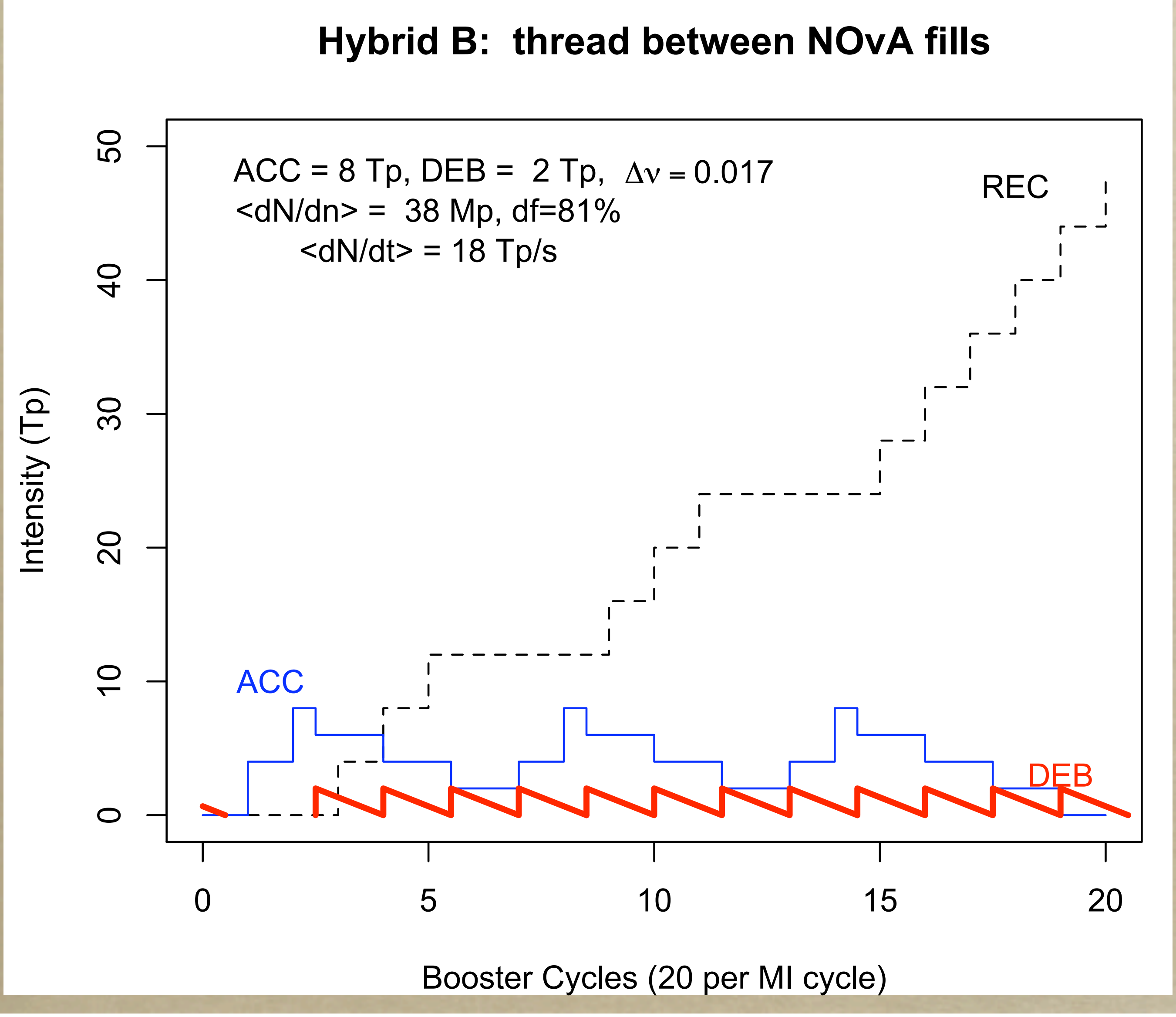


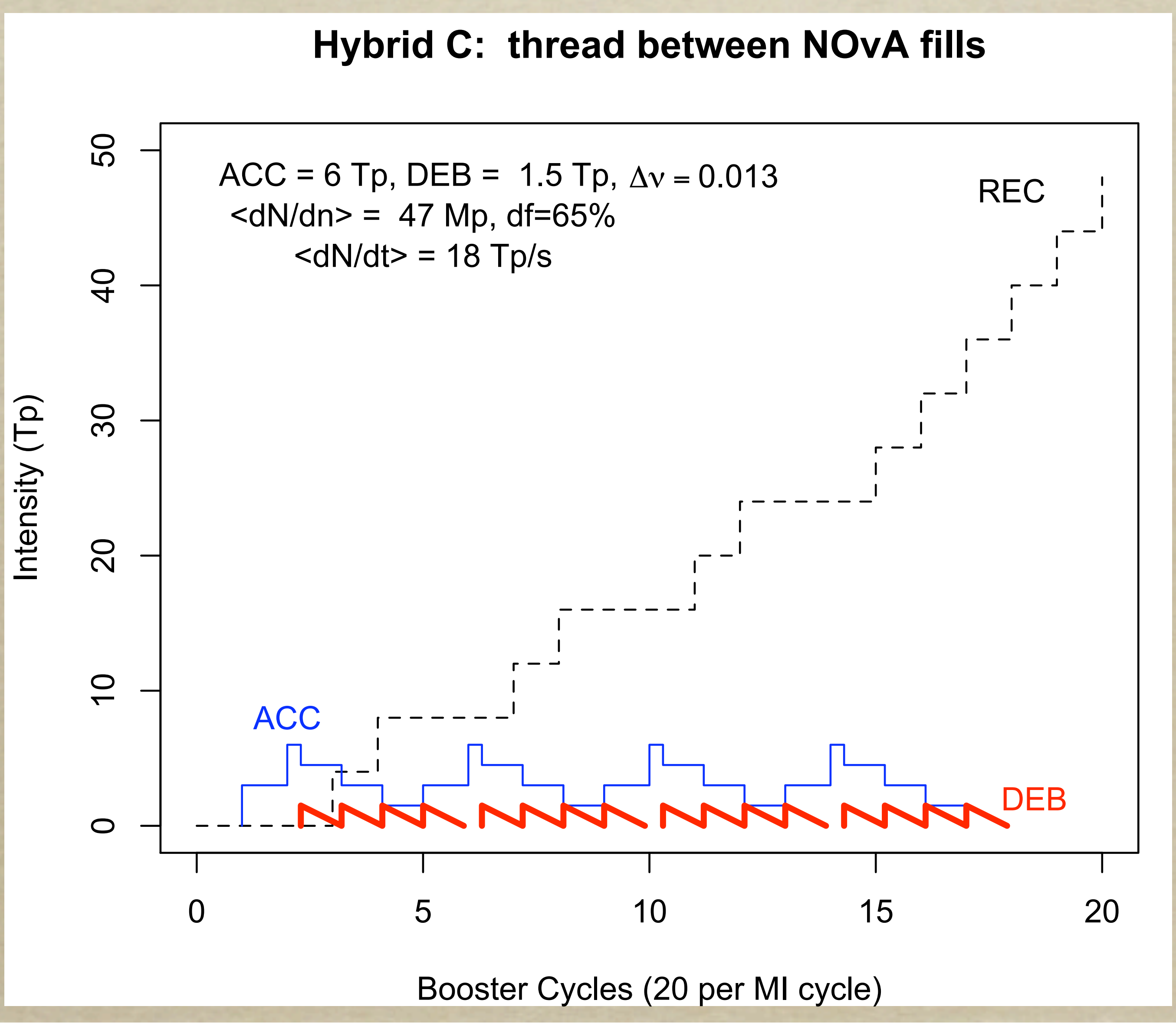


- *With threading, can split accumulated beam into 4 lower intensity bunches and transfer to the Debuncher one-at-a-time…*
- *Requires fast rise/fall-time Recycler extraction kickers, similar to injection kicker system*

Threading through the Intensity Frontier

- *Also provides* ***flexibility*** *in operating scenario as learn to deal with high intensities, rates to the experiment, or other program planning issues along the way …   several variants are possible*





Scenario Feasibility

- *Requires a "duplicate" set of kicker magnets in the extraction region as exists in the Recycler injection region required for NOvA*
    - *Baseline assumed a "pulsed dipole" for extraction*
- *Technique has been non-controversial to relevant AD specialists, NOvA project, etc.*
- *One less RF system (DEB) required*

Injector Chain

- *Booster*
  - *must run at 15 Hz -- not part of Project* per se, *but needs to happen*
- *Recycler*
  - *injection line from Booster -- part of NOvA*
  - *removal of stochastic cooling, etc -- part of NOvA*
  - *extraction from Recycler -- part of Mu2e*
- *Recycler to P1 Beam Line*
  - *presently, the P1 Beam Line ties into Main Injector; must connect now to Recycler as well*

Side Note: Booster @ 15 Hz

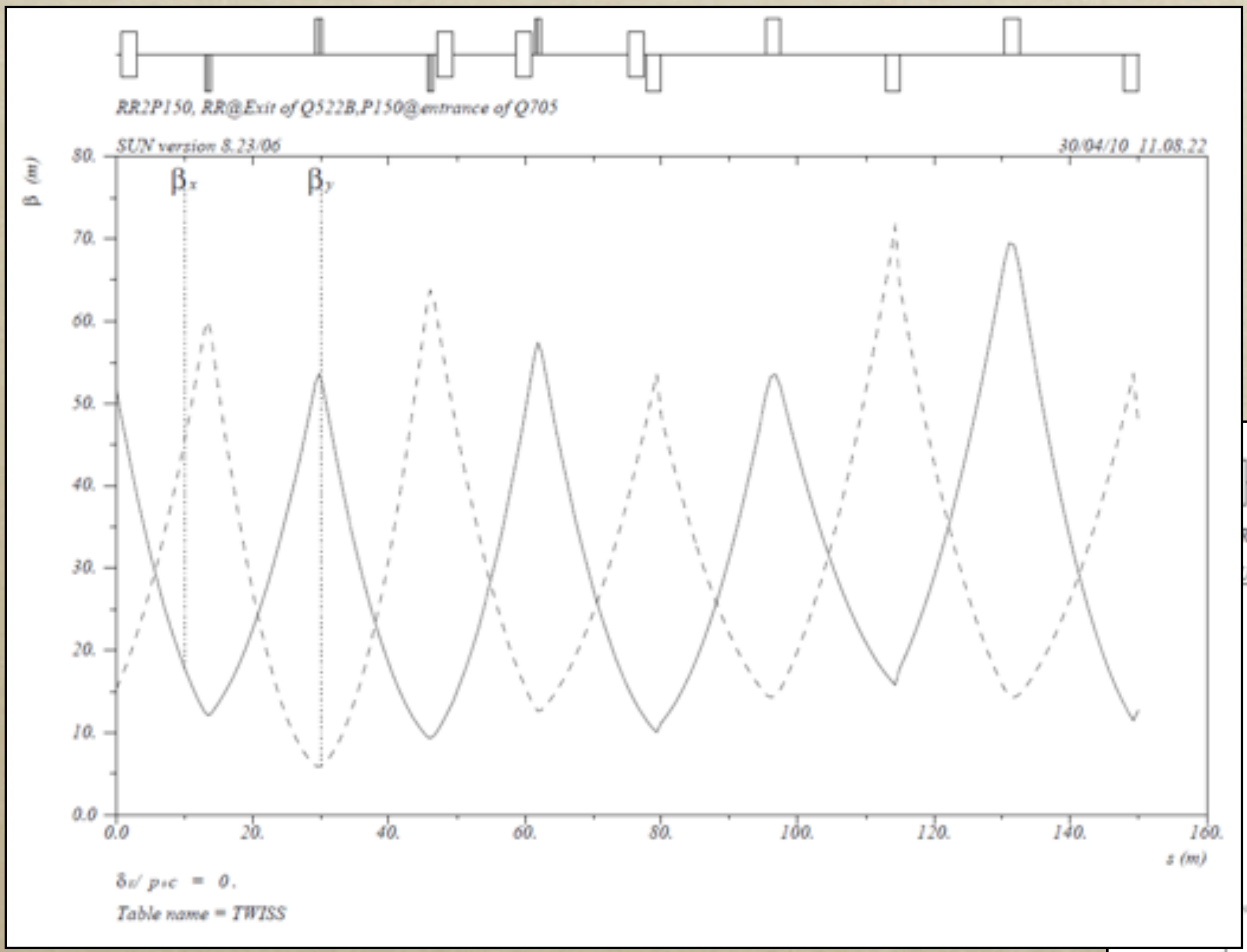
- *In order to use the remaining Booster cycles, all Booster components need to run at 15 Hz*
    - *Upgrades to Booster systems through the Proton Plan bring the repetition rate to 9-10 Hz; however, is not run at this rate now*
    - *Further upgrades to RF systems are necessary to reach 15 Hz (other components, such as kickers, etc., can run at this level already)*
    - *In NOvA era, 15 Hz is required to run microBooNE and Mu2e (both are approved experiments); also, helps with NOvA reliability as well*
    - *15 Hz upgrades have been identified and documented; currently, not part of a particular experiment or project, but rather seen as part of overall facility improvement plans*
- *Injector Task Force has been assembled -- W. Pellico, et al., reporting to AD Head*

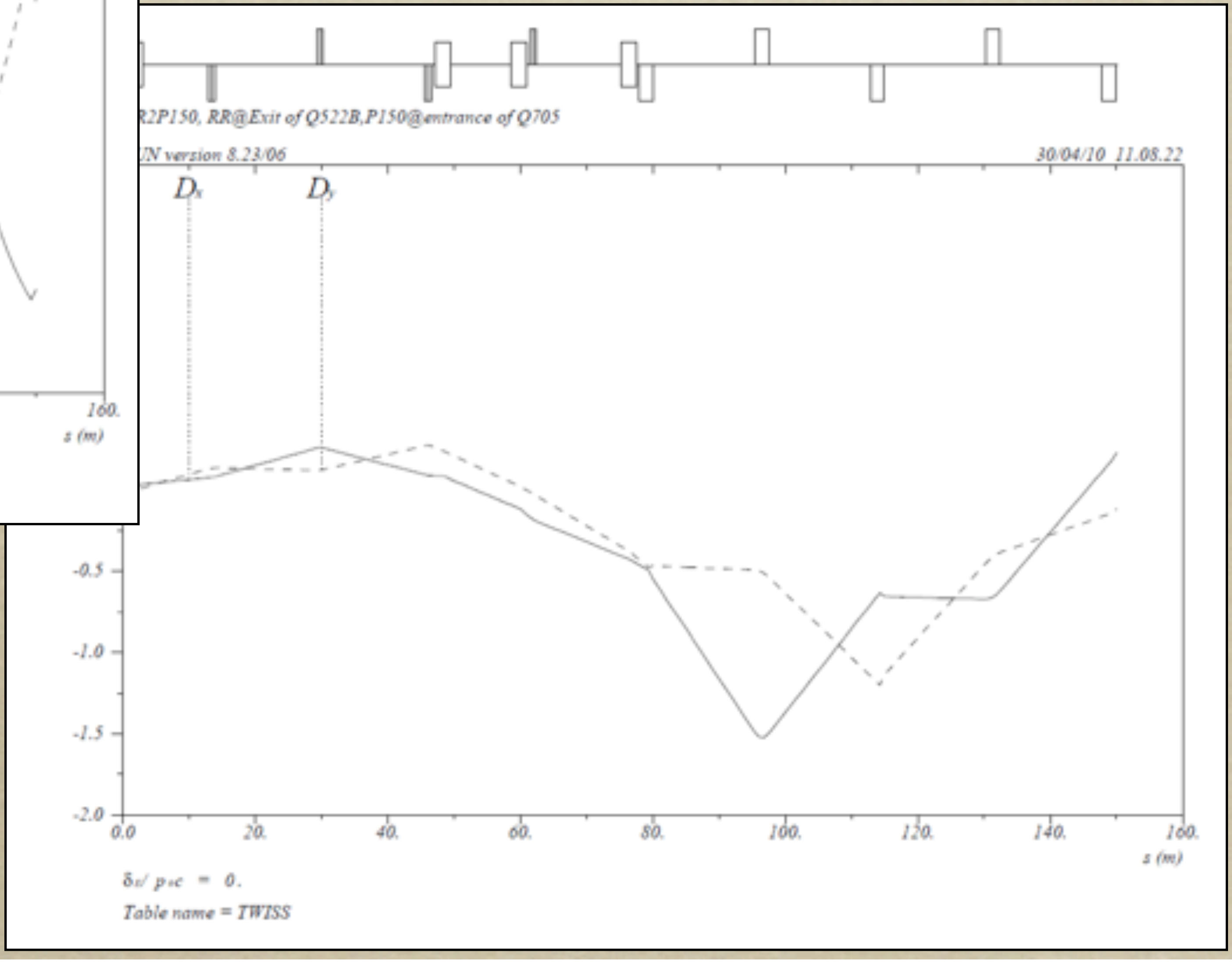
"How can *I* be a millionaire ... and never pay taxes? First, get a million dollars..." -- *Steve Martin*

Recycler to P1 Beam Line

- *First-order optics design performed by Meiqin Xiao, Main Injector Department*
  - *Room for kickers in the lattice (same as injection kickers), and extraction Lambertson*
  - *optical focusing matched between Recycler and P1*
  - *dispersion wave is small; can be worked on…*
- *Being laid out in CAD program by AD/ME*
- *Should be enough input for CD-1-level design and cost estimating to begin*

Recycler to P1 Beam Line



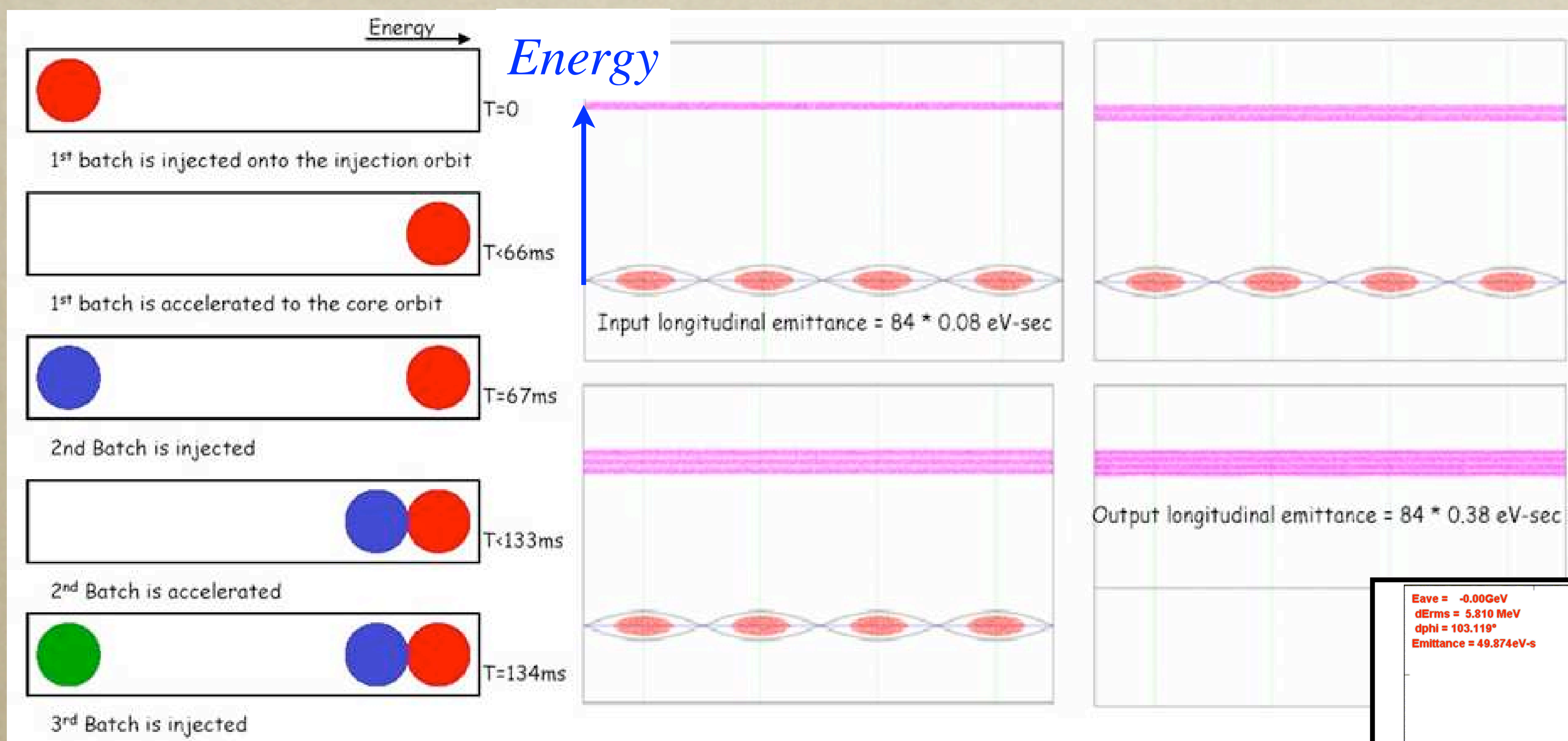


Collaboration Meeting 3 Jun 2010

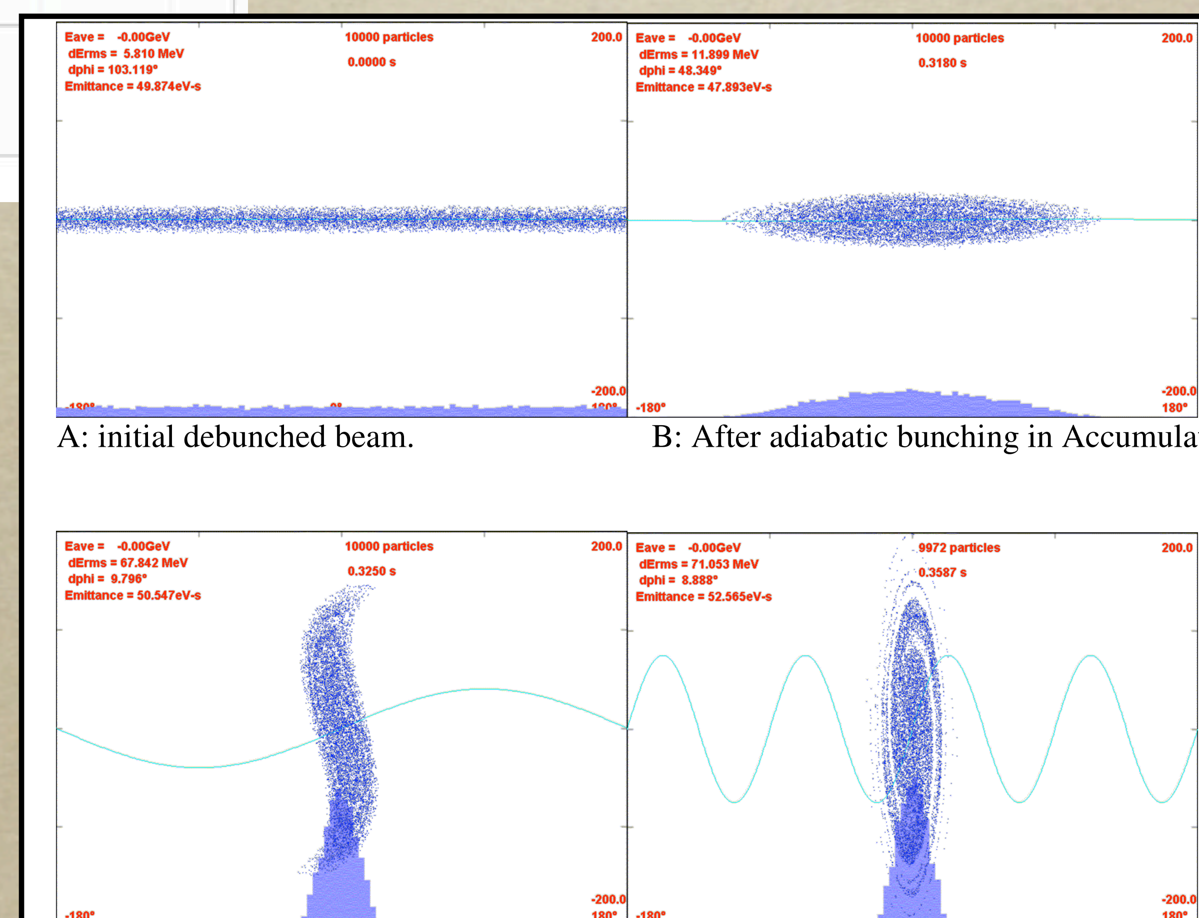
Storage Rings

- *RF Systems*
  - *S. Werkema heading up; received models from C. Bhat; adding impedances, beam loading, etc.*
  - *D. Peterson, EE, helping w/ RF systems requirements*
- *Kicker Systems*
  - *D. Vander Meulen heading up; NOvA kicker technique and technologies adaptable*
- *Aperture Improvements*
  - *straightforward; being handled by present pbar personnel*
- *Ring Transfer System*
  - *transfers between the two rings -- needs some aperture improvements*
  - *present "bottle necks" due to vacuum systems -- requirements are less for Mu2e*

Bunch Formation



- *momentum stack in Accumulator -- three batches from Booster, not four as shown*



A: initial debunched beam.

B: After adiabatic bunching in Accumulato

C: After ϕ-E rotation in Debuncher

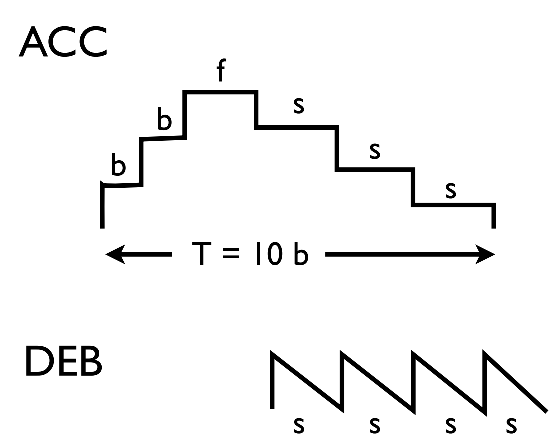
D: After h=4 bunching in Debuncher.

- *form* ***four*** *bunches; x-fer to Debuncher one-at-a-time*
- *30-40 nsec bunch, Δp/p ~ 0.5% (rms)*

Bunch Formation Time

- *RF voltages are determined by*
  - *momentum stacking manipulations*
  - *bunch formation time*
- *Time to stack last batch and form 4 bunches affects overall time left for slow spill*

Stacking and Bunch Formation Time



$$3s + f = T - 2b = 8b$$

$$s = (8b - f)/3$$

$$df = 4s/T = (16 - 2f/b)/15$$

f = b/2	===>	df = 100%
f = 3b/4	===>	df = 97%
f = b	===>	df = 93%
		etc.

Does not include "end effects" of slow spill, etc.

Comparisons

	Expt Cycle (BOO)	BOO pulses per Cycle	BOO intensity (Tp)	DEB intensity (Tp)	inst. <dp/dn> (Mp)	ave. <dp/dt> (Tp/s)	NOvA off <dp/dt> (Tp/s)	DEB sp. Chg. dnu
BASELINE	10	3	4	12	34	18	18	0.100
Full Rate (g-2) A	1	1	4	1	113	18	60	0.008
Full Rate (g-2) B	1	1	3	0.75	85	18	45	0.006
Hybrid A	10	3	4	3	34	18	18	0.025
Hybrid B	6	2	4	2	38	18	20	0.017
Hybrid C	4	2	3	1.5	47	18	22.5	0.013

- *Accumulator requires 53 MHz system for momentum stacking (as in Proposal) and a 2.4 MHz (h=4) system for bunch formation (625 kHz (h=1) in proposal).*
- *Debuncher requires h=4 system (**no** h=1).*
- *Bunch formation in Accumulator takes between 20-30 ms**

**See D. Neuffer, Fermilab-CONF-09-513-APC*

Compare Kicker Requirements

Mu2e Scenarios

	Expt Cycle (BOO)	Cycle time (ms)	Spills/Cycle	Cycles/MI	bunch form time (ms)	spill time (ms)	duty fact	NOvA Off duty fact
BASELINE	10	666.7	1	2	133.3	600	90%	90%
Full Rate (g-2) A	1	66.7	4	6	(REC)	15	27%	90%
Full Rate (g-2) B	1	66.7	4	8	(REC)	15	36%	90%
Hybrid A	10	666.7	4	2	33.3	150	90%	90%
Hybrid B	6	400.0	4	3	33.3	90	81%	90%
Hybrid C	4	266.7	4	4	20.0	54	65%	81%

If build to Hybrid B, can also work for A

TRANSFER KICKERS

	max rate (Hz)				*ave rate (Hz)*				*ave rate (Hz; NOvA off)*			
	REC out	ACC in	ACC out	DEB in	REC out	ACC in	ACC out	DEB in	REC out	ACC in	ACC out	DEB in
BASELINE	*dipole*	15	pulsed	pulsed	*n/a*	4.5	1.5	1.5	*n/a*	4.5	1.5	1.5
Full Rate (g-2) A	15	15	60	60	4.5	4.5	18	18	15	15	60	60
Full Rate (g-2) B	15	15	60	60	6	6	24	24	15	15	60	60
Hybrid A	15	15	6	6	4.5	4.5	6	6	4.5	4.5	6	6
Hybrid B	15	15	10	10	4.5	4.5	9	9	5	5	10	10
Hybrid C	15	15	16	16	6	6	12	12	7.5	7.5	15	15

Note: NOvA inj. kickers: 12/20x15 = 9 Hz (ave)
Booster ext. kickers: 15 Hz (ave)

Radiation Safety

- *Effort led by T. Leveling; A. Sondgeroth assisting; help from N. Duff (PPD; Health Physicist)*
- *Beam throughput -- proposal: 18 Tp/s*
    - *generating documents with upper limit of ~25 Tp/s; Leveling making first pass at a new radiation shielding assessment for 'pbar' storage rings*
- *NEPA -- have had meetings with FESS, ES&H*
    - *does not appear to be a big concern for us, though discussions with ES&H Section continue*
    - *beam power much less than today's site average; just distributed differently for Mu2e*
- *e-Berm -- AD/RSO favors this; still investigating*
- *Tony looking at modular septa designs, for extraction region*
- *will also be checking out "Chipmonk" (rad monitor) design; can work at Mu2e rates, or need new electronics for use around Mu2e berm, buildings?*

Beam Throughput and Radiation Safety

- *New particle rates for the "pbar" rings:*
  - *presently, Debuncher/Accumulator receive approximately 25x10^{10} particles per hour; for Mu2e, expecting ~2x10^{13}/sec*
    - *Total beam intensity ~4 times pbar record*
    - *Peak current ~70 times present record*
  - *1% loss per cycle (scaling) ➜ ~290 W of beam loss power*
    - *BOO: ~500 W total, ~1 W/m (300 W, 0.6 W/m in uncontrolled regions)*
    - *extraction region will be higher loss; special mitigation required here*
- *Storage Rings will require new Rad Safety system(s)*
  - *passive system not enough; need system similar to Booster system*

Extraction

- *Choices of Resonance*
  - *half vs third integer*
- *Space Charge Simulations*
- *"RF Knock Out"*
- *MI beam tests*

Mu2e: High Bunch Charge

- *Space Charge will be an issue in this scenario...*
  - *For N particles **uniformly** distributed about the ring,*

$$\Delta\nu_{s.c.} = \frac{3 r_0 N}{2\epsilon\gamma^2 (v/c)} = \frac{3\ (1.5\times 10^{-18})(1.2\times 10^{13})}{2\ (20\pi\times 10^{-6})(9.5^2)} \approx 0.005$$

  - *Include "bunching factor":* $\mathcal{B} \approx \dfrac{1700\ \text{nsec}}{40\ \text{nsec}\cdot\sqrt{2\pi}} \approx 17$

  - *Thus, expect at "design parameters":* $\Delta\nu_{s.c.} \approx 0.1$

- *Note: helped, somewhat, by large momentum spread -- spreads out beam horizontally*

Extraction w/ space charge

The Space Charge Effect in Slow Extraction by Third Integer Resonance

Yu.Senichev, V.Balandin
Institute for Nuclear Research of RAS,
60-th October Anniversary prosp., 7a, Moscow, 117312, Russia

EPAC94

1 INTRODUCTION

With the development and construction of high intensive beam accelerators and storage rings more and more attention is being focussed on the problem of the self-field effect of accelerated particles on the stability of their motion. This problem endures second birth, which connected with, on the one hand, requirement to know more exactly the parameters of beam and on other hand, with more powerful computers for an investigation. At first the analytical methods were used in mainly, among which the equations of Kapchinsky and Sacherer take significant place. They gave necessary information about the envelope of high intensive beam with the elliptical distribution. As far as the improvement of computer technology, the new numer-

$$\frac{e}{p_0 c} A_{sc}(x,y) - \frac{e}{p_0 c} A_{ex}(x,y), \qquad (1)$$

where A_{sc}, Φ_{sc} - the vector and the scalar potential of the space charge field and A_{ex} -the vector potential of the external field. It is assumed here, that the transverse currents are absent:

$$A_{sc} = \frac{v}{c}\Phi_{sc}(1 + hx), \qquad (2)$$

where v is the longitudinal velocity equal for all particles. The vector potential of the external field has components up to the octupole inclusive:

$$-\frac{e}{cp_0} A_{ex}(x,y) = hx + (K + h^2)\frac{x^2}{2} - K\frac{y^2}{2} +$$

- *Phase space distortions in the presence of space charge, near third-integer resonance, can be very significant*

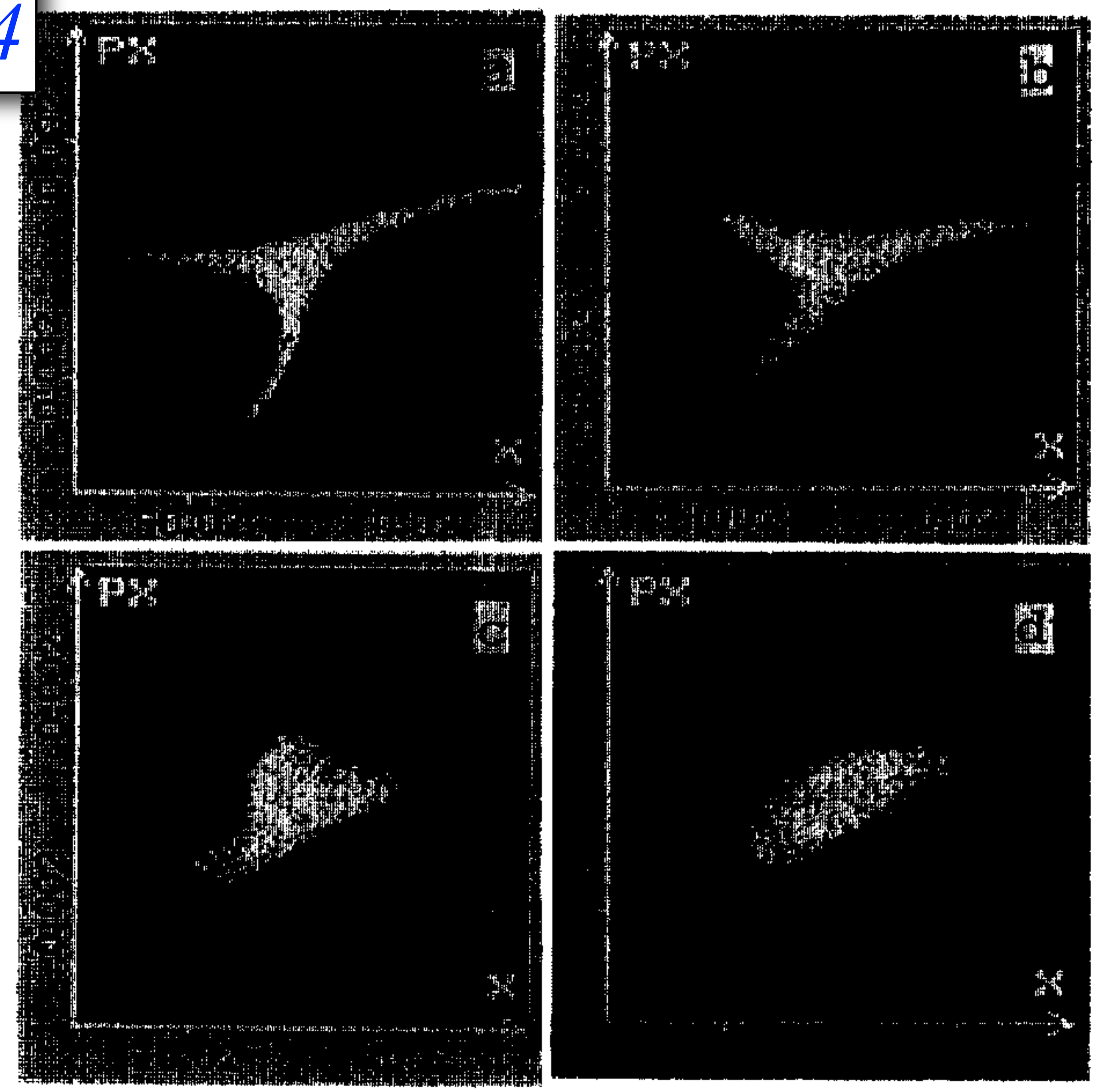
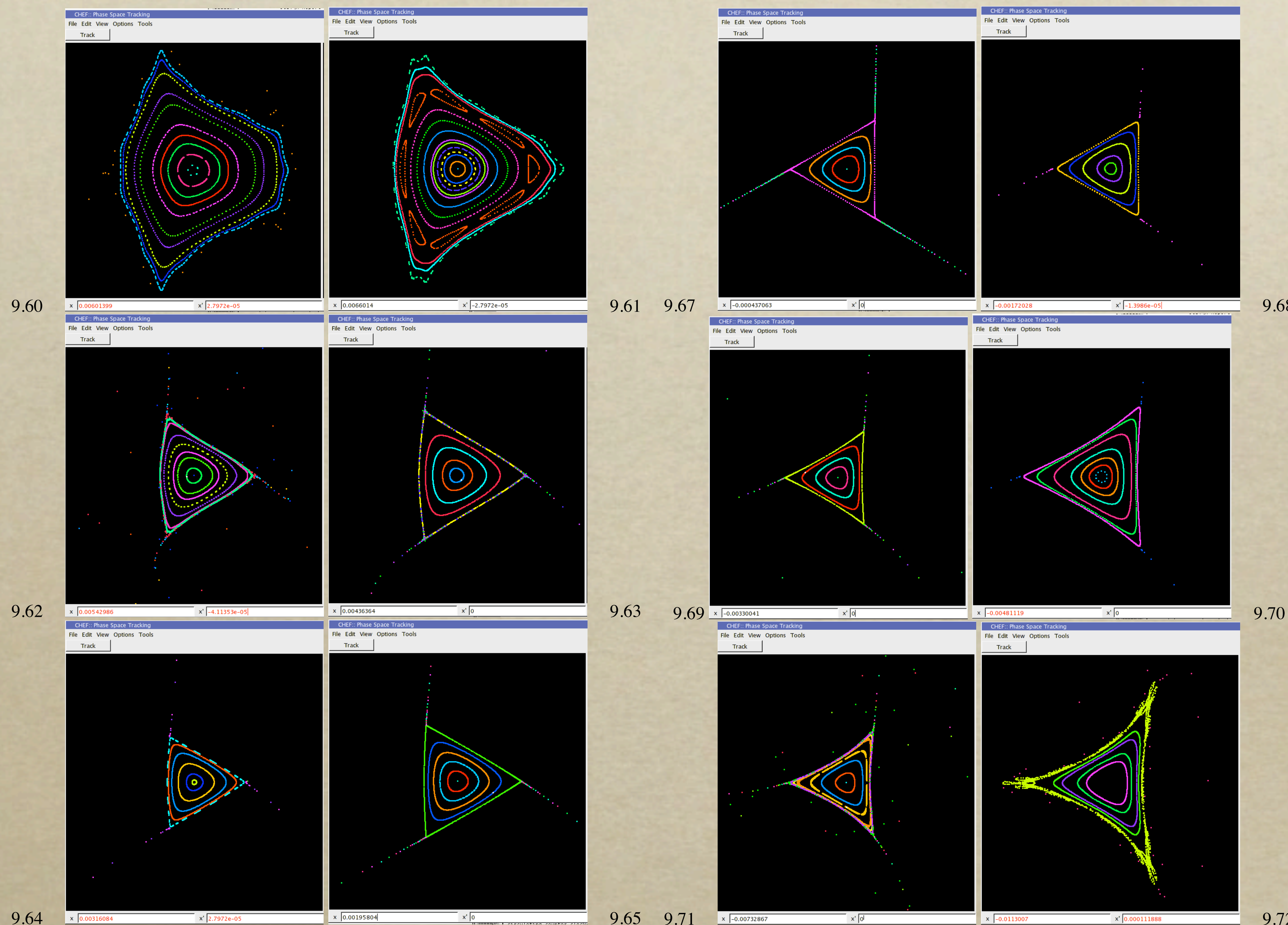


Figure 2: The phase portraits of the beam at a)$\Delta\nu_L$=0.01, b)$\Delta\nu_L$=0.03, c)$\Delta\nu_L$=0.06 and d)$\Delta\nu_L$=0.1

Exploration of Tune Space*

Tune space of Debuncher, near third-integer (tune ~ 29/3)

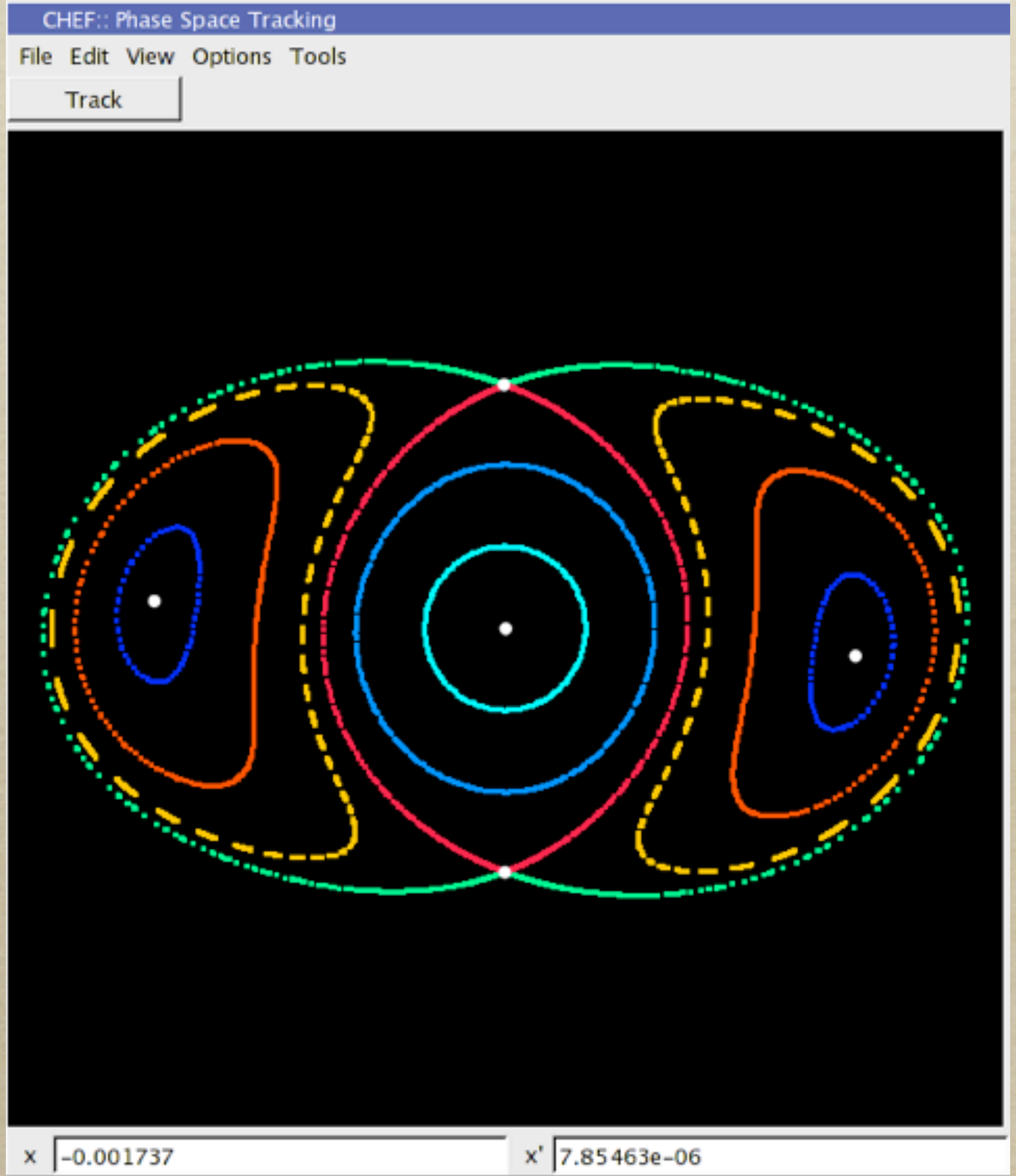
Need to control tune to within ~0.05 of resonance



**Michelotti*

Half-integer Extraction

- *Work has begun to study half-integer extraction*
  - *phase space*
  - *corrector parameters*
- *Much experience at Fermilab -- MR, Tev, MI*
- *New technique is evolving which might deal with large tune distribution*



Michelotti

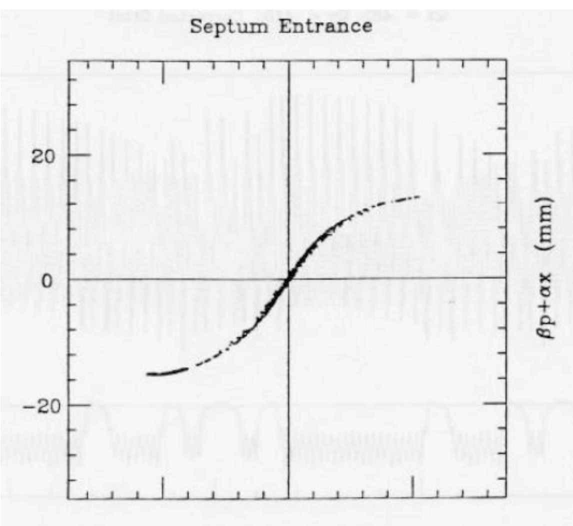
Historical Half-Integer Approach

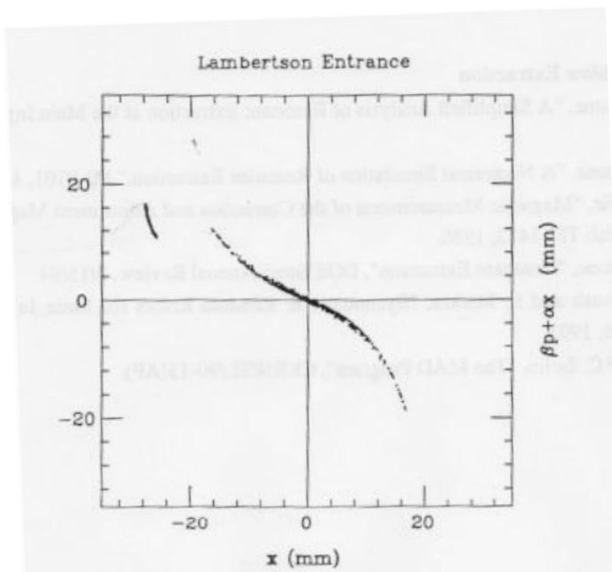
Resonant Extraction from the MI @ 120 GeV/c:

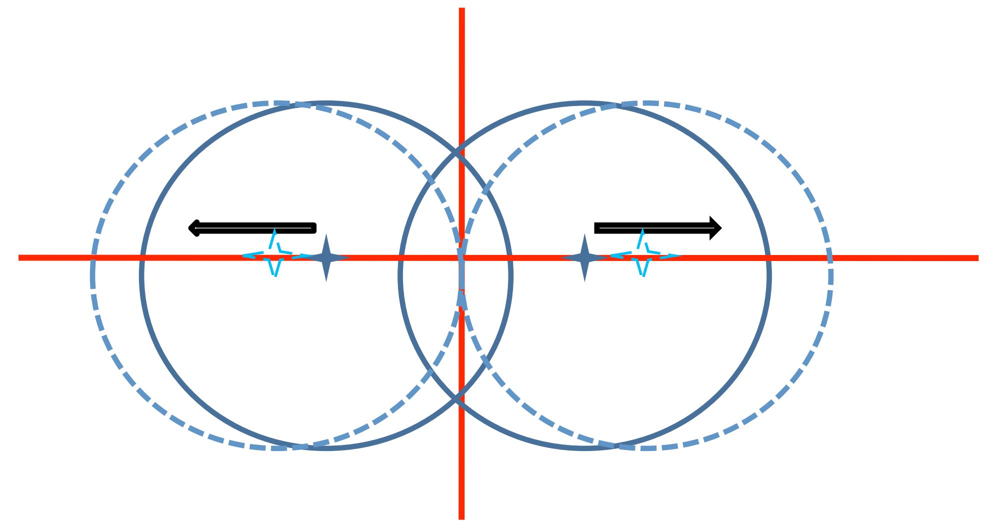
Cx = +5, & $\Delta p_{95}/p = \pm 0.04\%$:

Tune Spread $\Delta_{95} = 0.015 \pm 0.002$

$\Rightarrow$ ~12 mm *separation at Lambertson*







$$\left[x\pm\left(\frac{q_2\beta}{6\lambda}\right)^{1/2}\sin(\psi/2)\right]^2+\left[x'\mp\left(\frac{q_2\beta}{6\lambda}\right)^{1/2}\cos(\psi/2)\right]^2=\left(\frac{\Delta\beta}{6\lambda}\right)$$

Assuming a fixed circle radius the q_2 driving term is systematically increased to pull the circles apart, thereby decreasing the stable area to zero.

This approach to resonant extraction was used exclusively in the Main Ring, again in the Tevatron, and still today in the Main Injector.

- *J. Johnstone*
  - *see Mu2e-doc-576*

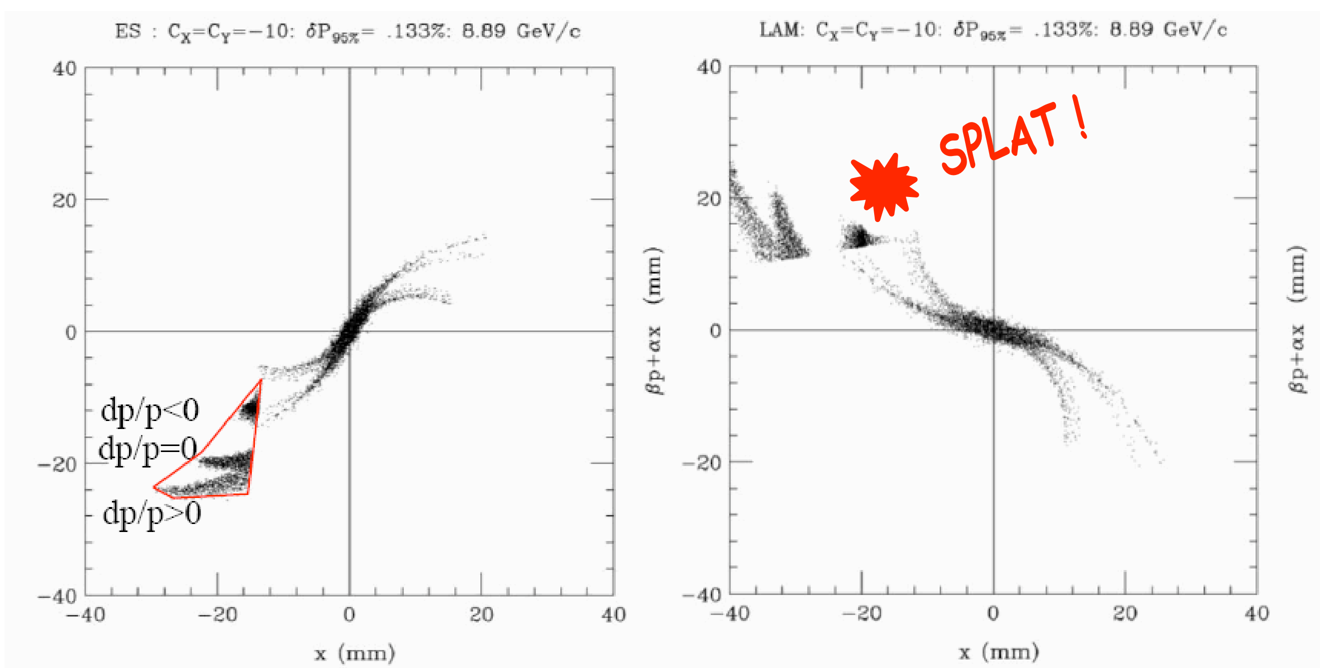
JJ's Previous Study: Recycler

Simulated Extraction from the Recycler (actually MI) @ 8.9 GeV/c:

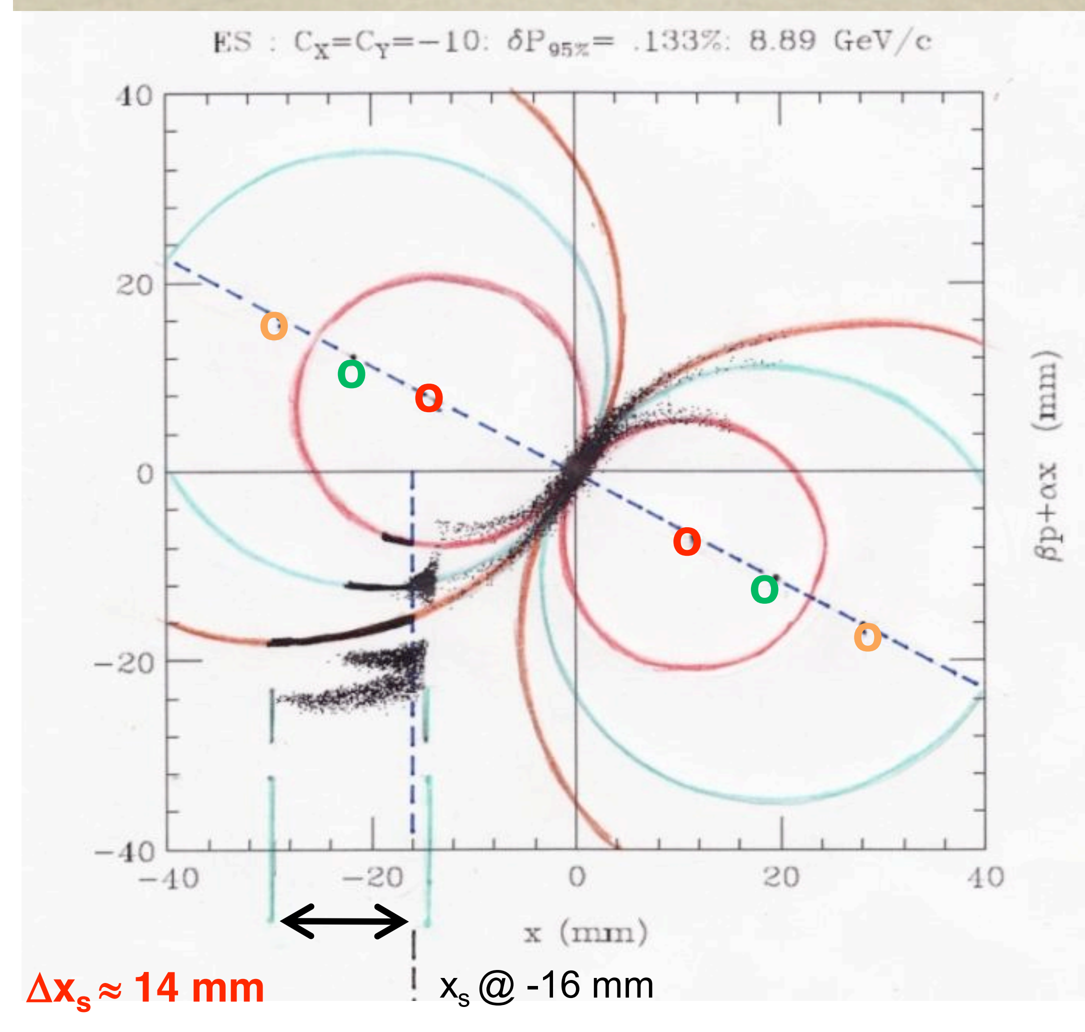
C_x = -10, & $\Delta p_{95}/p$ = ±0.133% :

Tune Spread Δ_{95} = 0.025 ± 0.0133

⇒ ***ZERO*** *separation at Lambertson !*



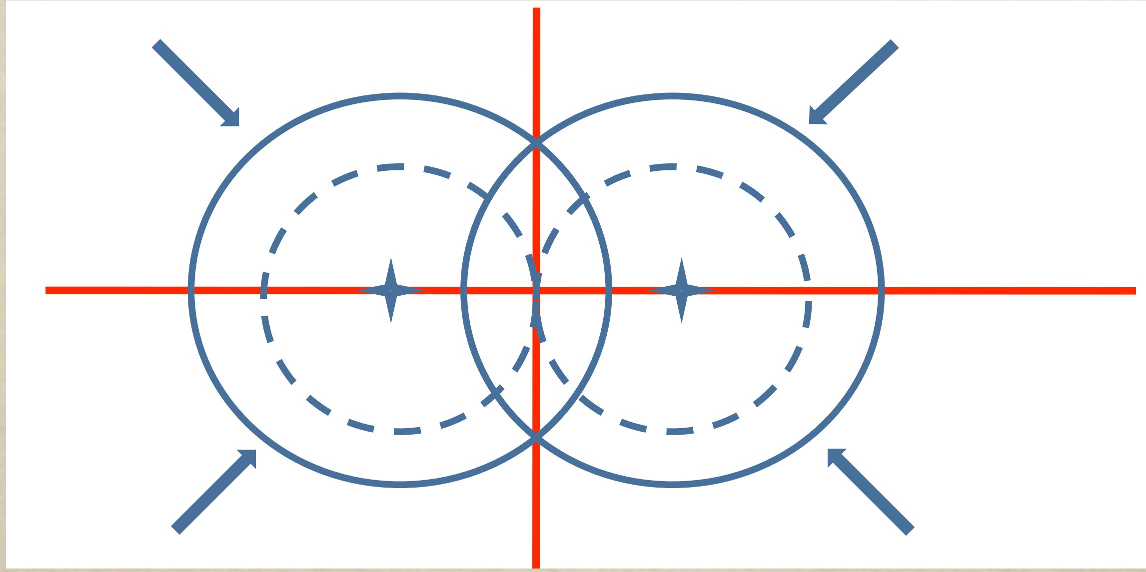
Different "circles" for different momenta (different tunes)



- *Large tune spread seemed problematic…*

New Idea

- *Instead, use a zeroth-harmonic quad circuit to vary the radius of circles, rather than pulling them apart…*



$\because \Delta = \Delta_{|initial} \rightarrow q_2$ covers the total extraction of emittance ε, irrespective of Δp/p:

- variation of the separatrices' circle radii are identical over the course of extraction;
- step-size at the septum is identical for all Δp/p, and;
- Extracted beam phase-space trajectories are identical for the entire range of Δp/p.

Looks promising; attempting to try out in MI…

Summary

- The addition of a q_0 tune circuit has potential for greatly improving half-integer extraction in the event of a large tune spread.
- Because of the great similarity between the MI and Recycler lattices this technique can be tested in MI – the MI has all the necessary components already installed.

Ω

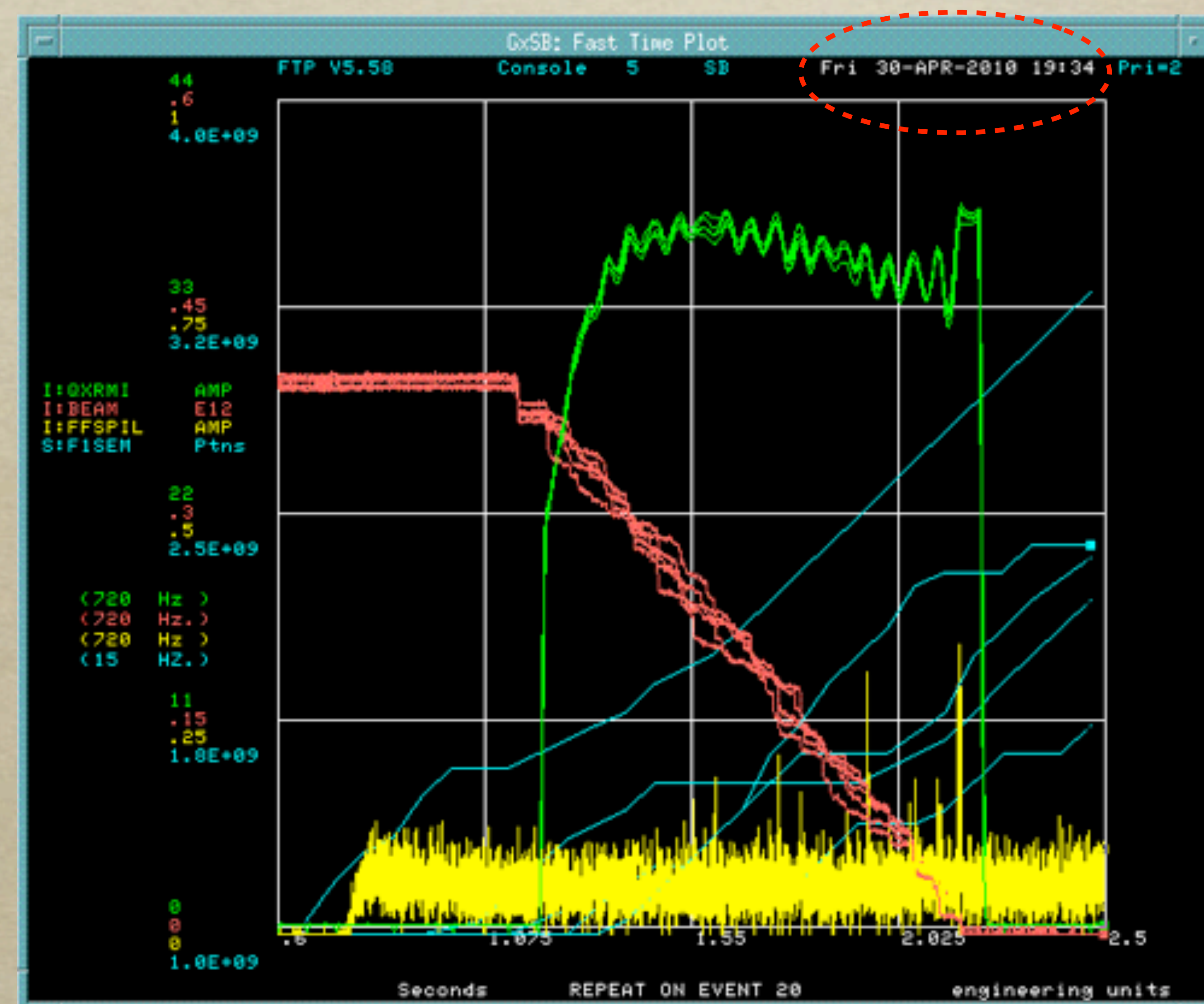
Extraction Studies

- *Several "teams" are looking at extraction*
  - *Johnstone, Michelotti (as noted above)*
  - *Werkema, Nagaslaev -- simple model, but with a space charge code (ORBIT, from ORNL)*
  - *Amundson, Spentzouris -- full 3-D space charge simulations*
- *Beginning to perform beam studies in the MI*

Recent Beam Studies

- *So far, checking out instrumentation, establishing spills of appropriate duration from MI, using standard approach*

- *Will re-configure quad circuits for test of new phase space manipulation*

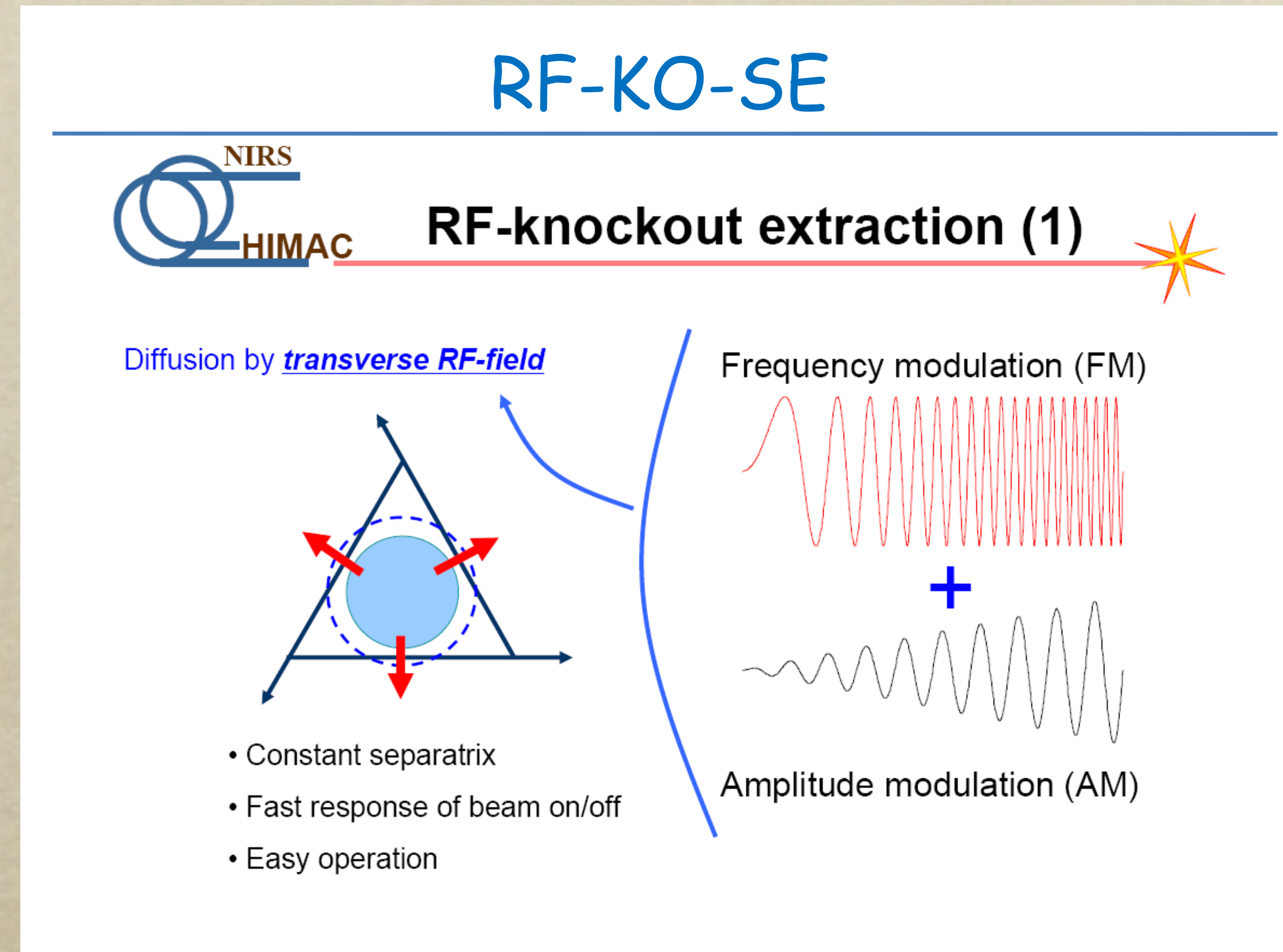


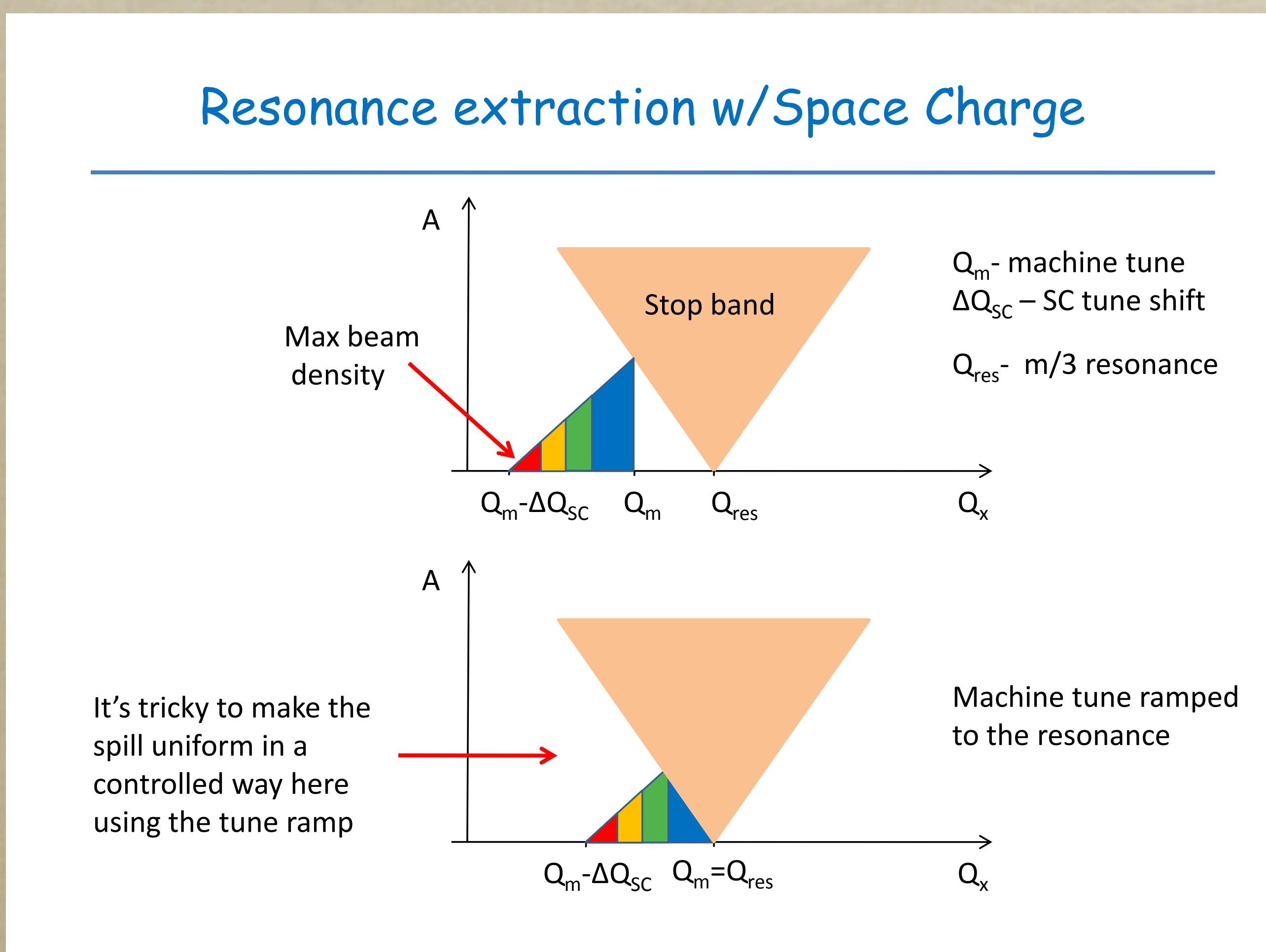
RF Knock-Out

- *New proposed technique for alleviating space charge (or OTHER tune spread sources) effects during extration*
- *Utilizes an AM/FM fast kicker (RF device) to kick the beam transversely, increasing the beam emittance toward the unstable regions of phase space*
- *Used in small medical synchrotrons to fine-control spills to patients*

RFKO

- *See V. Nagaslaev, Mu2e-doc-775*

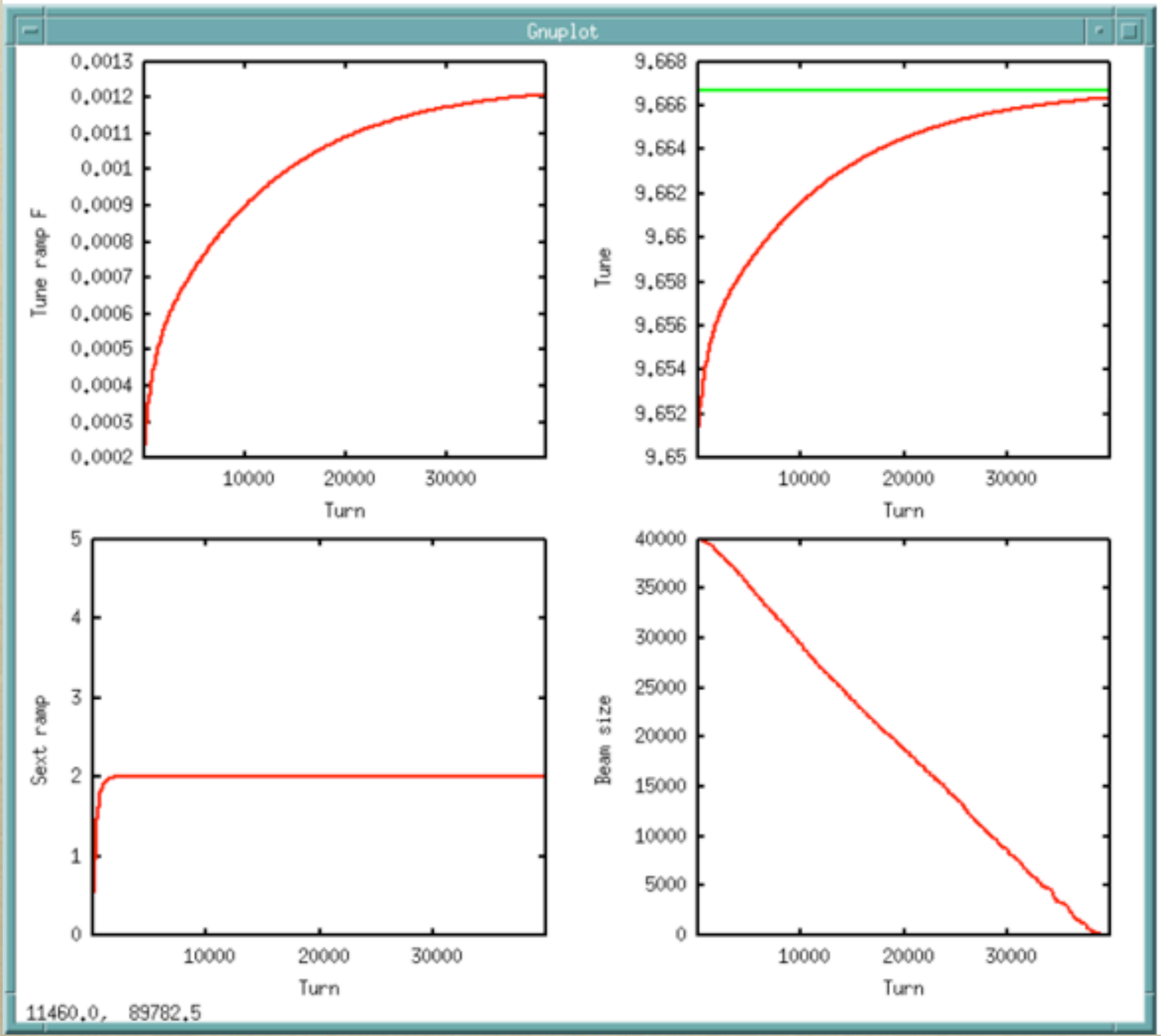




Collaboration Meeting 3 Jun 2010

RF Knock Out

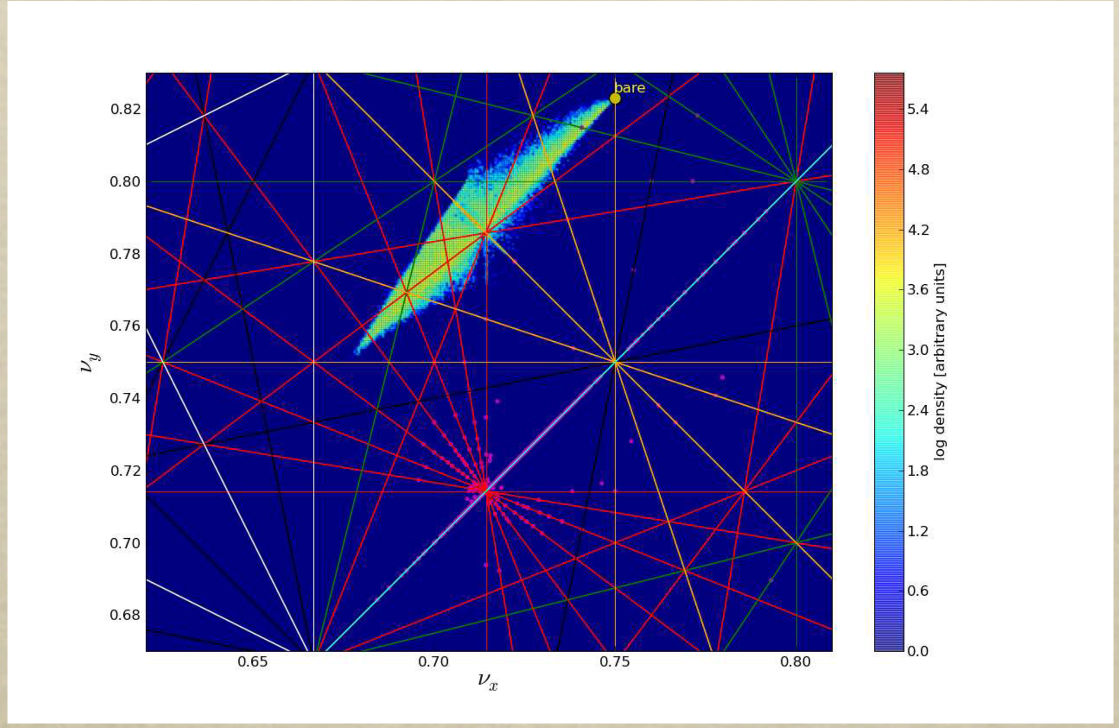
- *VN's simulation, utilizing RFKO in feedback mode, third-integer resonance, with space charge included*



Space Charge Calculations

- *3-D space charge simulations continue*
- *presently debugging new re-write of the code*

Arnold diffusion? Resonance streaming?



At highest intensity: observation of early loss particles "streaming" along resonance lines in tune-space. (Notice outlier dots lying on resonance lines near lower center of picture. Expand the figure if necessary.) Behavior similar to this is sometimes called "Arnold diffusion" or, less frequently, "resonance streaming."

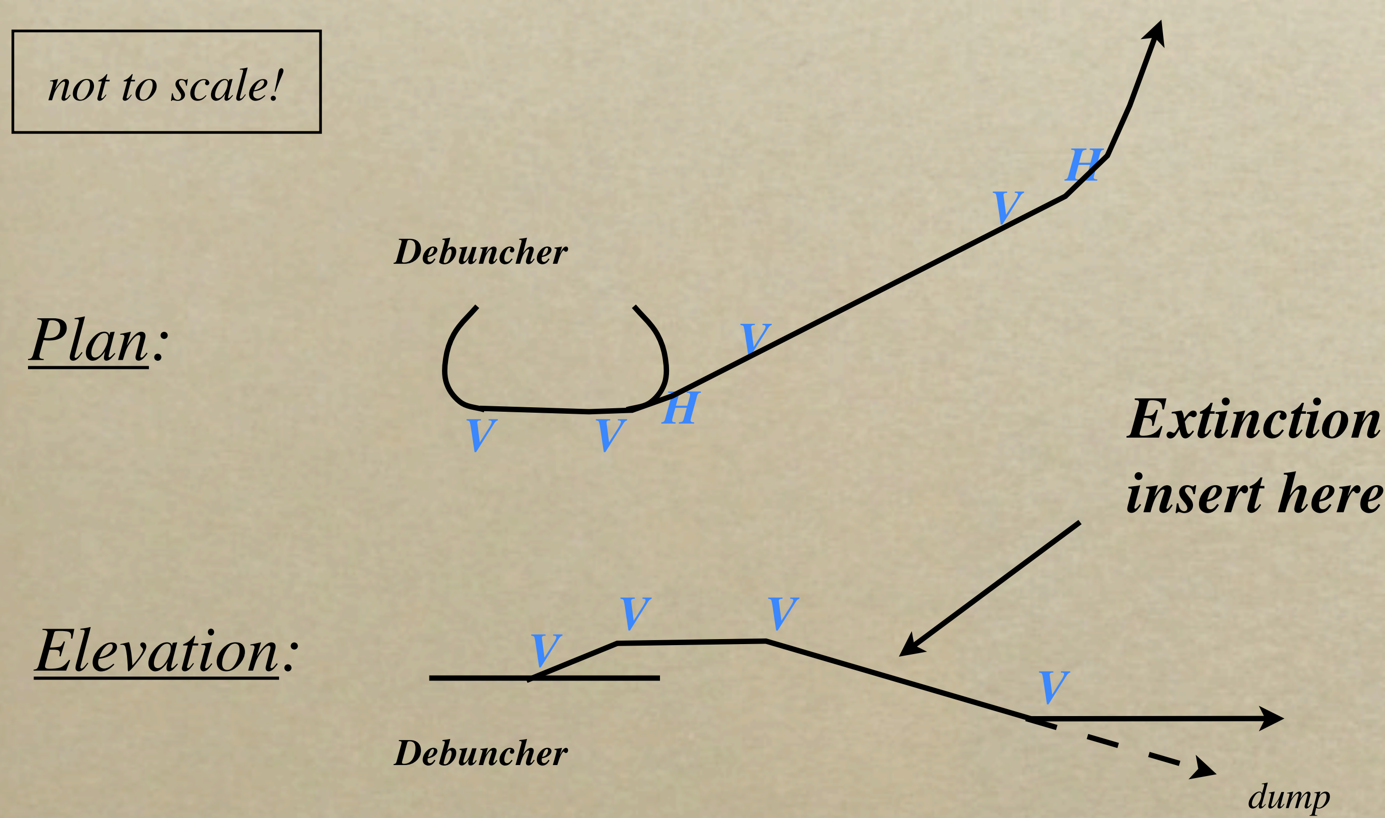
(Thanks to Jim Amundson for this figure.)

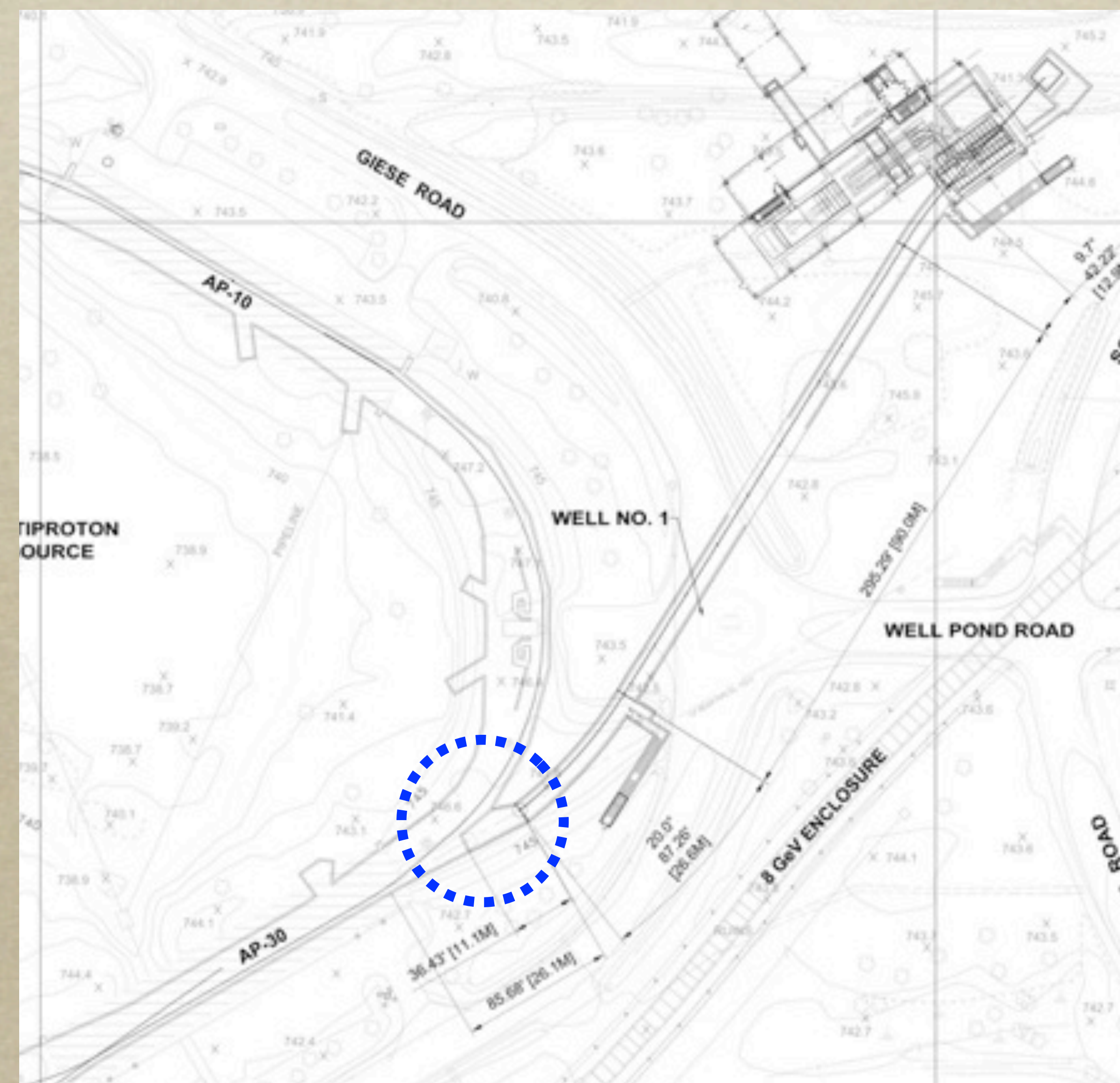
Mu2e Beam Transport Line

- *Beam Line Components*
- *Siting*
- *Extinction Insert -- see E. Prebys' talk*

Mu2e Beam Line

- *Design work proceeding, utilizing existing "stub" in ring tunnel as the final exit point*

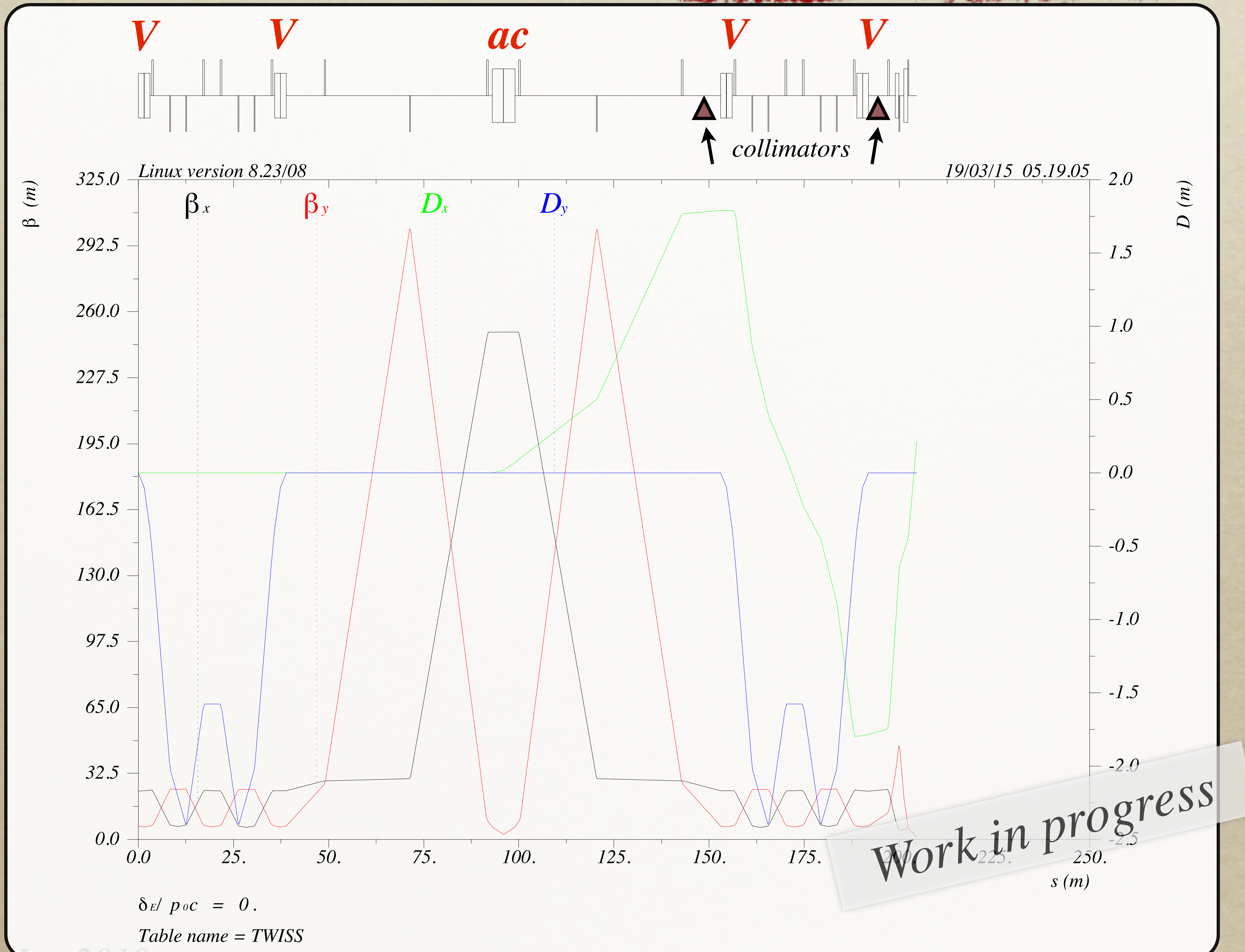




Work in progress

Beam Line Optics (so far...)*

Here, ends before the final H bend, and still need the final focus onto the target; Also, will optimize extinction insert optics



*C. Johnstone

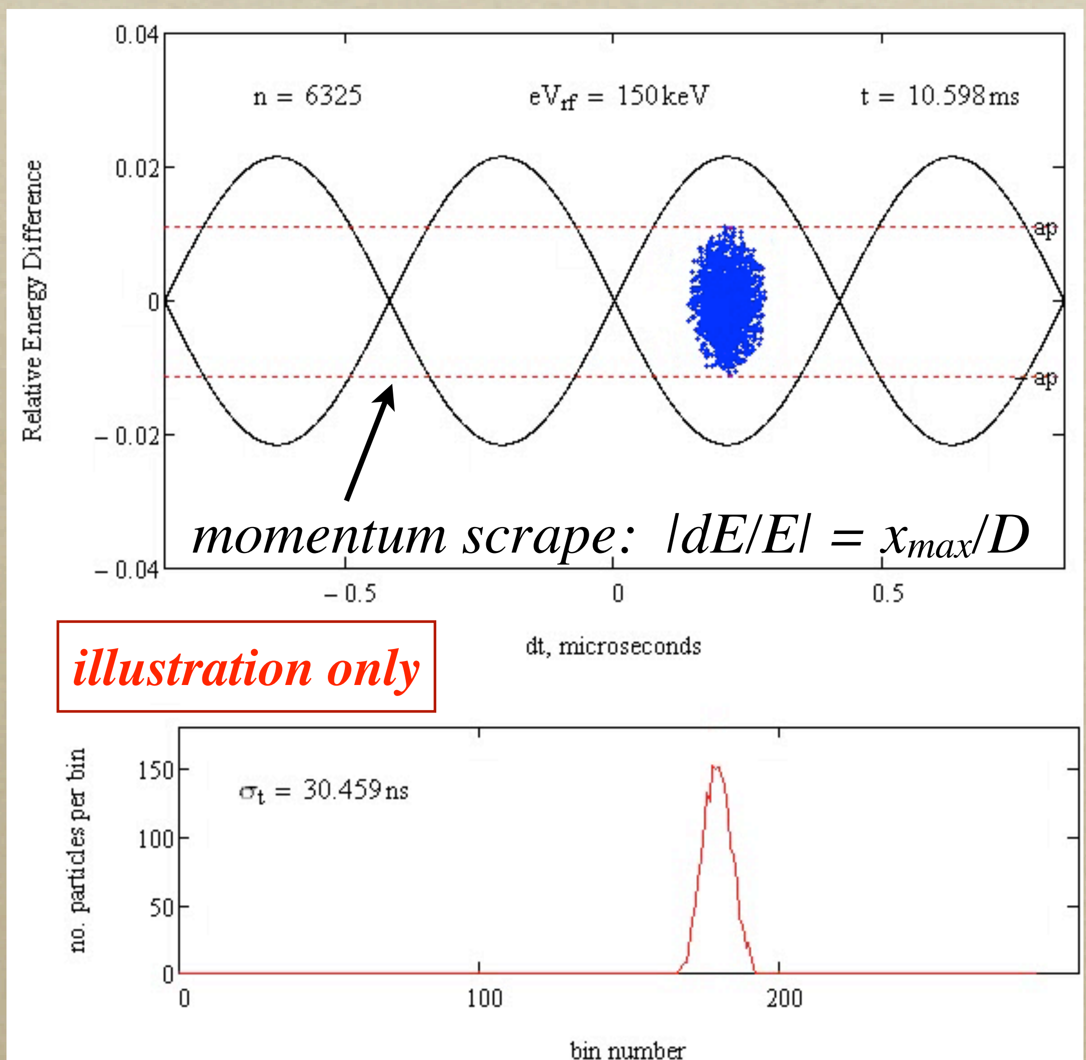
Beam Line Issues

- *The optical design, as is, is longer than desired*
- *Working to shorten the initial bend regions*
  - *can interlace the strong horizontal bending with the weaker vertical bending at upstream end*
  - *may be space to save along the extinction insert, as well as near the end of the beam line*
- *Desire to keep further away from creek...*

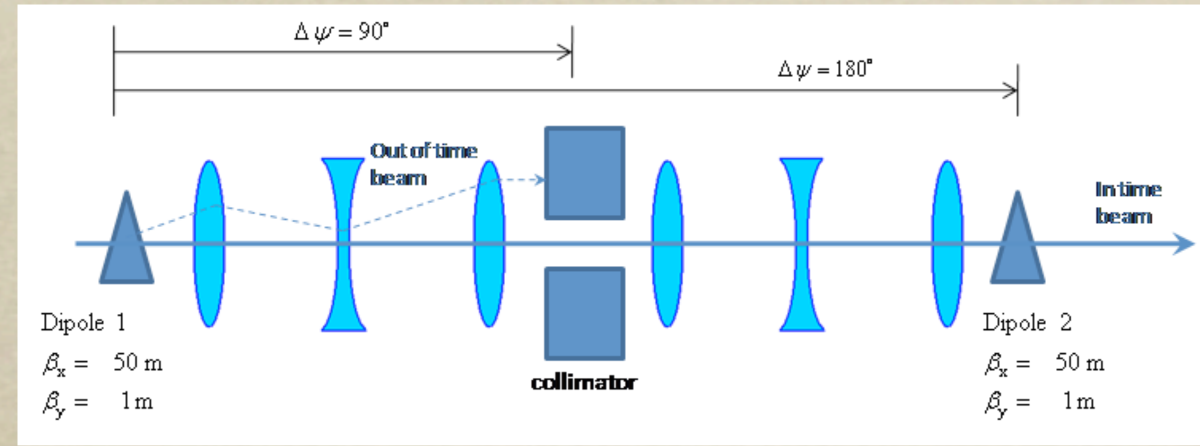
Mu2e Extinction

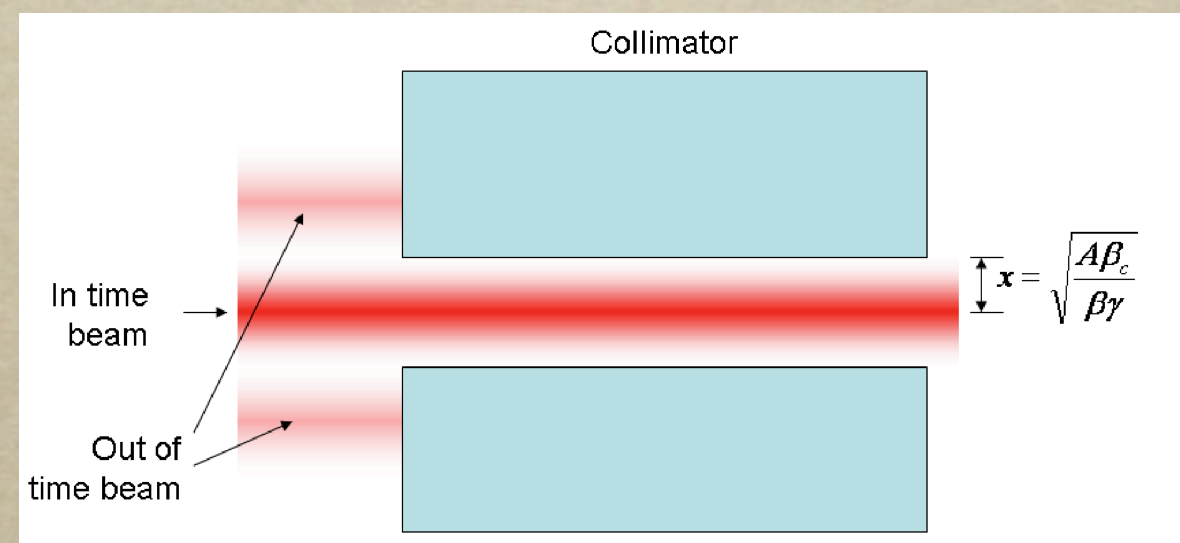
See E. Prebys' talk

- *Internal --*



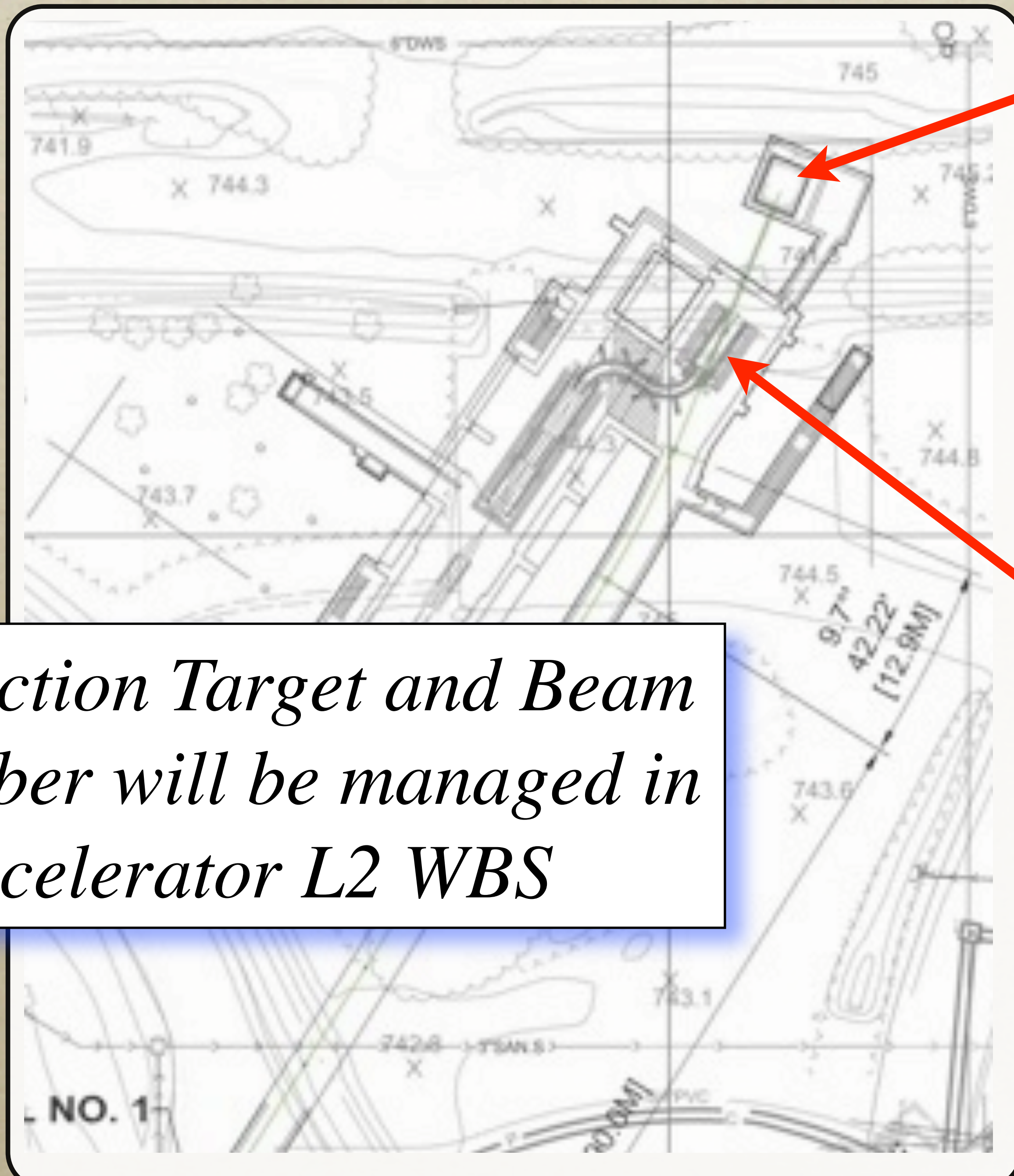
- *External --*





Target and Absorber

See R. Coleman's talk



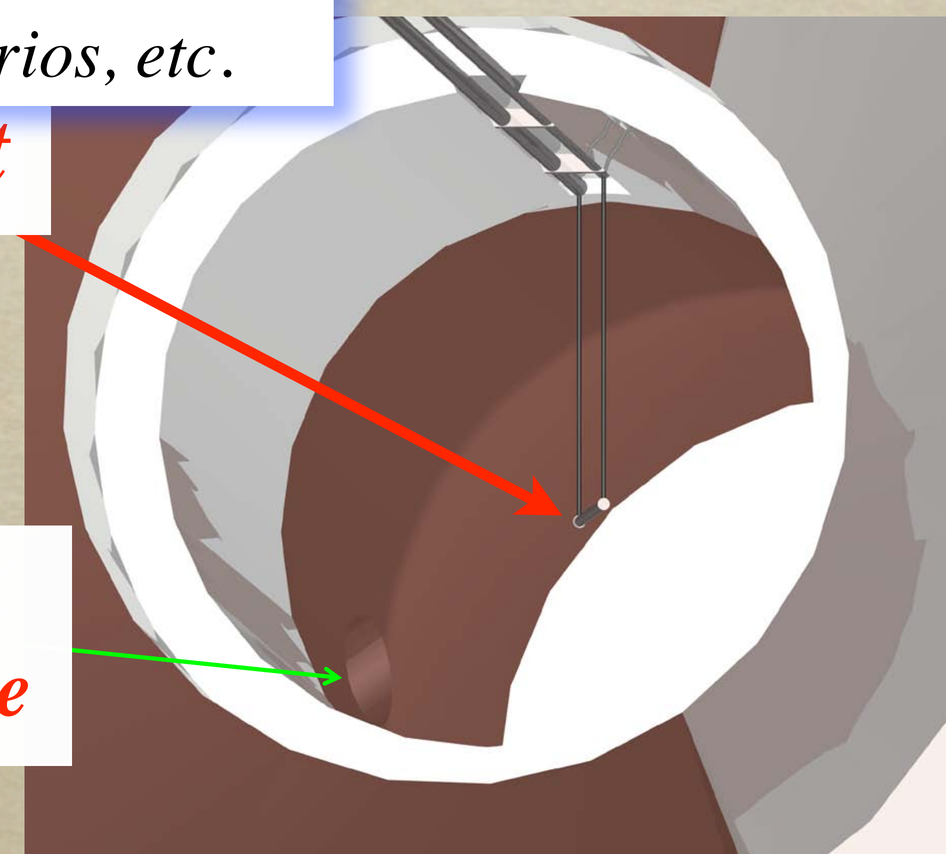
absorber

~25 kW ave. beam power

heating/cooling, replacement scenarios, etc.

target

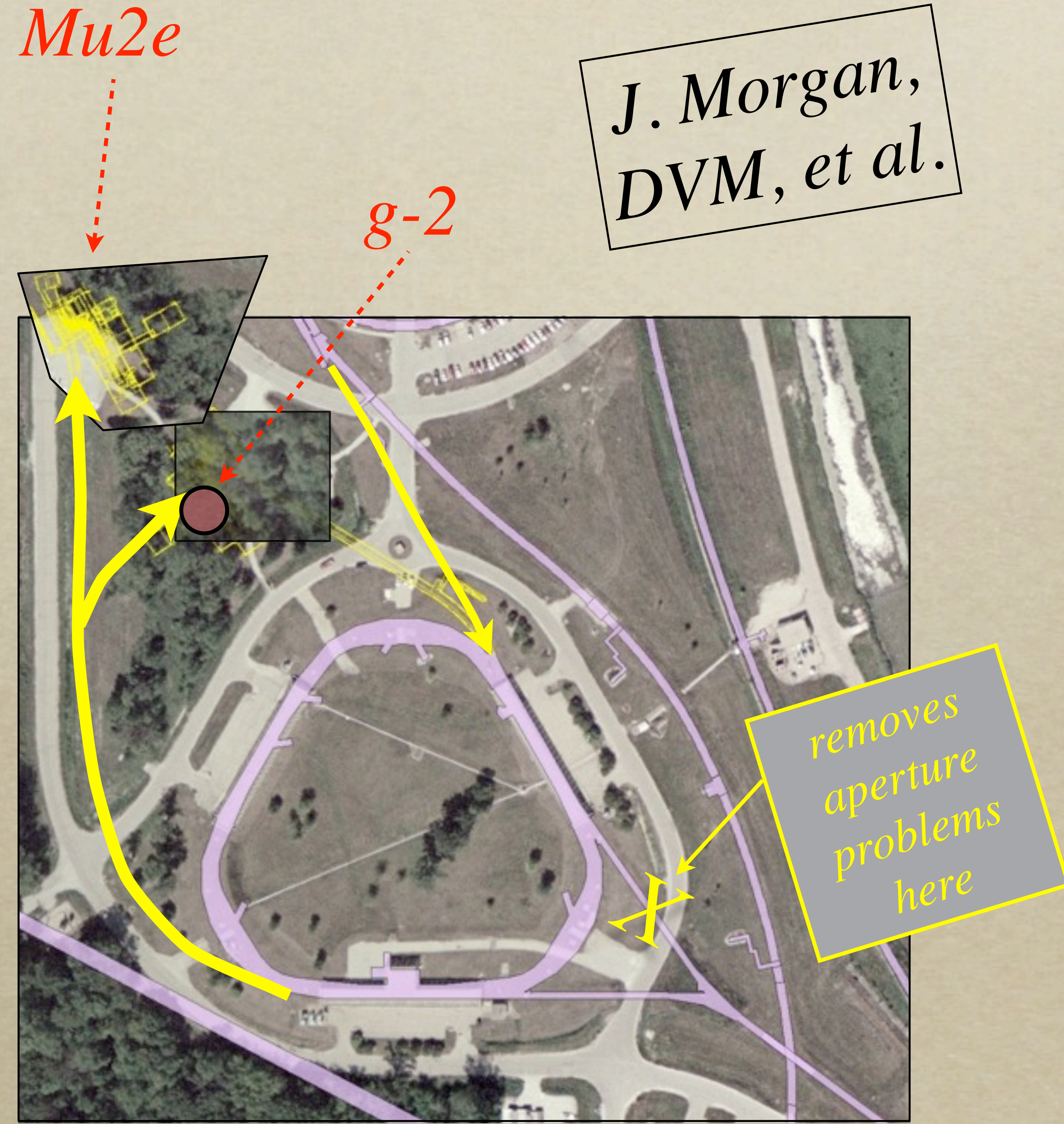
Production Target and Beam Absorber will be managed in the Accelerator L2 WBS



p beam entrance

A Possible Alternative, for CD-1

- *Direct Feed from Booster*
  - *may be optimal, if no g-2 or "other" 8 GeV program*
  - *or, may be optimal IF there IS g-2, and the lab wants to have a "program facility"...*
  - *removes dependency on MI/Recycler to be running*



Beam Requirements -- Mu2e

- *Generating list of 'requirements'*
- *Receiving further input from collaboration*
- *Mu2e-doc-585*

Mu2e Accelerator and Beams
Identifcation of Requirements

Definitions:

Strawman *list of possible parameters:*

Parameter	*Design*	*Limit*	*Unit*	*Notes*
Time between microbunches	**1685**	1685	ns	
Design length of slow spill period	**150**	>20	ms	
Duty factor	**90**	>75	%	
Beam Line Transmission Window (centered on microbunch center)	**200**		ns	
Transmission Window jitter (rms)	**5**	<10	ns	
Extinction Level	1.00E-09			Is there a "limit"?
A = no. particles to target outside transmission window				
B = no. particles to target through transmission window				[put into separate document?]
X =A/B				
(need specification of an "extinction function" (of time)?)				
Average integrated intensity per microbunch on target	**35**	<50	Mp	
rms spread of microbunch intensity on target	20	<50	%	
rms Cycle-to-Cycle intensity variation	20	<100	%	
Time Average dN/dt on target (averaged over many beam cycles)	**18**	<25	Tp/s	
Transverse spot size on target, rms	**1**	<2	mm	
		>0.5	mm	
Transverse beam divergence on target (above assumed to be "round")	0.1	<0.3	mr	any real req. here?
Vertical beam steering range on target	+/- 100		mm	---
Horizontal beam steering range on target	+/- 10		mm	these are fake
Vernier beam steering adjustment size	0.05		mm	numbers;
Vertical beam angle adjustment range on target	10		mr	needs real work
Horizontal beam angle adjustment range on target	1		mr	!!!!
Vernier beam angle adjustment size	0.01		mr	---
Microbunch total length	**150**	<200	ns	
Microbunch rms length	**30**	<40	ns	

Beam Requirements Document

Fermilab

Mu2e

MU2E PROTON BEAM REQUIREMENTS

DRAFT — DRAFT — DRAFT — DRAFT — DRAFT

M.J. SYPHERS

The basic requirements of the Mu2e experiment that need to be met by the accelerator complex include

- having pulses of protons reach the production target at a repeat period longer than the lifetime of muons in aluminum, which is approximately 864 ns.
- having the time distribution of particles reaching the target within a window of length approximately 150 ns, with essentially no particles outside of this window (for extinction level requirements, see [1]).
- delivering approximately 4×10^{20} protons on target (POT) during approximately 2 years of running.
- optimizing detector performance by having as high a duty factor as possible and as low an instantaneous rate as practical.

To meet these basic requirements, the Mu2e experiment utilizes the 1685 ns revolution period of the 8.9 GeV/c Debuncher ring to provide pulses of protons with this time interval to the production target. The Fermilab Booster synchrotron can readily produce 4×10^{12} (4 Tp) protons per cycle, and during the operation of the Main Injector (MI) for the NOvA experiment, 6 Booster cycles can be made available every MI cycle (1.333 s). To make use of the extra Booster cycles and provide beam to the experiment, the Booster is required to operate at its full 15 Hz rate. The proposal is to use three consecutive Booster cycles to accumulate protons into the Fermilab Accumulator ring for Mu2e, and to repeat the entire procedure twice per MI cycle. This provides an average rate to the experiment of 18 Tp/s. With 50% efficiency over a two year period, this generates 5×10^{20} POT with comfortable margin.

To optimize detector performance the experiment desires beam to arrive with relatively high duty factor ($90\%^{+}$). At the average rate of 18 Tp/s, and pulses arriving every 1685 ns 90% of the time, each pulse will have a total intensity of approximately 34 Mp, consistent with the anticipated capabilities of the present detector design.

Date: 24 May 2010.

TABLE 1. Mu2e Beam Parameters

Parameter	Design	Limit	Unit	Notes
Booster synchrotron repetition rate	15	>13.5	Hz	
Time between beam pulses	1685	1685	ns	Debuncher revolution period
Length of slow spill period	150	>20	ms	
Duty factor	90	>75	%	
Beam Line Transmission Window (centered on beam pulse center)	200	200	ns	relevant for AC dipole specs
Transmission Window jitter (rms)	5	<10	ns	
Extinction Level	10^{-9}			see [1]
Average intensity per pulse on target	34	<50	Mp	
rms spread of pulse intensity on target	20	<50	%	
rms Cycle-to-Cycle intensity variation	20	<100	%	
Time Average dN/dt on target (averaged over many beam cycles)	18	<25	Tp/s	relevant for NOvA-off conditions; also, for rad safety
Target rms transverse spot size (assumed "round")	1	<2 >0.5	mm mm	
Target rms transverse beam divergence (assumed "round")	0.5	<20	mr	see [3]
Beam pulse total length	150	<200	ns	
Beam pulse rms length	30	<40	ns	

REFERENCES

[1] Extinction Requirements Document, Mu2e-doc-xxx.
[2] Production Target Requirements Document, Mu2e-doc-yyy.
[3] Design value consistent with emittance of 30 π mm-mr; Limit value consistent with target size.

Collaboration Meeting 3 Jun 2010

Mu2e Accelerator Systems -- WBS

- *Work Breakdown Structure has been drafted*
- *Some detail down to “Levels 5, 6”*
  - *WBS Dictionary being developed to define terms*

1.2 Mu2e Accelerator
- 1.2.1 Project Management
- 1.2.2 Proton Source
  - 1.2.2.1 Booster upgrades
- 1.2.3 Recycler
  - 1.2.3.1 Recycler R&D
  - 1.2.3.2 Injection System
  - 1.2.3.3 RF Systems
  - 1.2.3.4 Instrumentation
  - 1.2.3.5 Cooling Removal
  - 1.2.3.6 Extraction System
- 1.2.4 Storage Rings
  - 1.2.4.1 Storage Rings R&D
  - 1.2.4.2 Beam Lines
  - 1.2.4.3 RF Systems
  - 1.2.4.4 Instrumentation
  - 1.2.4.5 Cooling Removal
  - 1.2.4.6 Beam Damper System
  - 1.2.4.7 Beam Abort System
  - 1.2.4.8 Infrastructure Improvements
- 1.2.5 Radiation Safety Improvements
  - 1.2.5.1 Rad Safety R&D
  - 1.2.5.2 REC-ACC Beam Line Upgrade
  - 1.2.5.3 ACC/DEB Tunnel/Buildings Upgrade
  - 1.2.5.4 External Beam Line
- 1.2.6 Resonant Extraction System
  - 1.2.6.1 Resonant Extraction R&D
  - 1.2.6.2 Resonant Extraction Hardware
- 1.2.7 External Beam Line
  - 1.2.7.1 Beam Line R&D
  - 1.2.7.2 Beam Transport
  - 1.2.7.3 Beam Line Dump
  - 1.2.7.4 Safety System
- 1.2.8 Extinction
  - 1.2.8.1 Extinction R&D
  - 1.2.8.2 Internal Extinction System
  - 1.2.8.3 External Extinction System
- 1.2.9 Target Station
  - 1.2.9.1 Targeting R&D
  - 1.2.9.2 Target
  - 1.2.9.3 Target Handling
  - 1.2.9.4 Absorber
  - 1.2.9.5 Shielding
  - 1.2.9.6 Cooling
  - 1.2.9.7 Instrumentation
- 1.2.10 Operations Preparation
  - 1.2.10.1 Application Codes
  - 1.2.10.2 Procedures Documentation

Mu2e Weekly Accelerator Meetings

- *Periodic meetings have been held, involving personnel from Particle Physics, Accelerator, Technical, Computing Divisions and Accelerator Physics Center*

Accelerator Working Group meets ~1/mo.

L2+L3's meet bi-weekly

Other meetings:
beam line
storage rings
production solenoid
extinction group
AC dipole
...

See: Accelerator sub-page at http://mu2e.fnal.gov/atwork/

MU2E-BEAM membership

MU2E-BEAM membership

amundson@FNAL.GOV	Jim Amundson	mokhov@FNAL.GOV	Nikolai Mokhov
ankenbrandt@FNAL.GOV	Chuck Ankenbrandt	wmolzon@UCI.EDU	William Molzon
rhbob@FNAL.GOV	Robert Bernstein	cmoore@FNAL.GOV	Craig Moore
cbhat@FNAL.GOV	Chandra Bhat	jpmorgan@FNAL.GOV	Jim Morgan
broemmel@FNAL.GOV	Dan Broemmelsiek	nsergei@FNAL.GOV	Sergei Nagaitsev
coleman@FNAL.GOV	Rick Coleman	vnagasl@FNAL.GOV	Vladimir Nagaslaev
macc@FNAL.GOV	Mary Anne Cummings	neuffer@FNAL.GOV	David Neuffer
fritzd@FNAL.GOV	Fritz DeJongh	ng@FNAL.GOV	Bill Ng
Drendel@FNAL.GOV	Brian Drendel	ostiguy@FNAL.GOV	Francois Ostiguy
drozhdin@FNAL.GOV	Sasha Drozhdin	peterson@FNAL.GOV	Dave Peterson
craigdukes@VIRGINIA.EDU	Craig Dukes	popovic@FNAL.GOV	Milorad Popovic
nevans1983@GMAIL.COM	Nick Evans	jpopp@YORK.CUNY.EDU	Jim Popp
sgeer@FNAL.GOV	Steve Geer	prebys@FNAL.GOV	Eric Prebys
g-gollin@UIUC.EDU	George Gollin	vspron@FNAL.GOV	Vitaly Pronskikh
harding@FNAL.GOV	David Harding	rakhno@FNAL.GOV	Igor Rakhno
dazhanghuang@GMAIL.COM	Dazhang Huang	rray@FNAL.GOV	Ron Ray
dej@FNAL.GOV	David Johnson	tjrob@FNAL.GOV	Tom Roberts
cjj@FNAL.GOV	Carol Johnstone	Scarpine@FNAL.GOV	Vic Scarpine
JJohnstone@FNAL.GOV	John Johnstone	shiltsev@FNAL.GOV	Vladimir Shiltsev
kahn@BNL.GOV	Stephen Kahn	spentz@FNAL.GOV	Panagiotis Spentzouris
kobilarc@FNAL.GOV	Thomas R. Kobilarcik	syphers@FNAL.GOV	Mike Syphers
yury@PHYSICS.BERKELEY.EDU	Yury Komolensky	vander@FNAL.GOV	Dave VanderMeulen
kopp@HEP.UTEXAS.EDU	Sacha Kopp	warner@FNAL.GOV	Arden Warner
lamm@FNAL.GOV	Michael Lamm	werkema@FNAL.GOV	Steve Werkema
leveling@FNAL.GOV	Tony Leveling	yamin@BNL.GOV	Yamin, Peter
PJLIMON@FNAL.GOV	Peter Limon	yonehara@FNAL.GOV	Katsuya Yonehara
maclachlan@FNAL.GOV	Jim MacLachlan	yosh@FNAL.GOV	Cary Yoshikawa
marshw@FNAL.GOV	Bill Marsh	*	
martens@FNAL.GOV	Mike Martens	* Total number of users subscribed to the list:	59
meghan.mcateer@GMAIL.COM	Meghan McAteer	* Total number of local host users on the list:	0
MICHELOTTI@FNAL.GOV	Leo Michelotti	*	
miller@BUPHY.BU.EDU	James Miller		

Participation

Good participation by Scientific Staff on many fronts:

Operating Scenario / Injectors

new 'hybrid' details - Syphers

kickers for Recycler - (NOvA)

tie-in to P1 line - Xiao

Booster - McAteer

Storage Rings efforts

rf requirements - Werkema, Peterson

beam line upgrades - Morgan

kicker requirements - Vander Meulen

beam/ring studies - Drendel

radiation safety - Leveling

Extraction Process

resonant extraction

- Michelotti, JJohnstone

rf ko enhancement - Nagaslaev

Extinction

internal, external - Prebys, TD, ...

monitoring - Prebys, Warner, Evans, ...

Participation

Continued...

Beam Line

optics layout - CJohnstone

extinction insert - CJohnstone, Prebys

radiation safety - Leveling

Production Target / Absorber

entrance trajectory - Coleman

absorber, cooling - Coleman, Popp

shielding -- Coleman, Mokhov, Pronskikh

target, handling - Coleman

Project Management

meetings, documents - Syphers, Ray

WBS

schedule to CD-1

risk assessment

manpower estimates -Syphers

scientific

engineering

Hopefully haven't left too many out, though I'm sure I have...

Also Keeping an Eye on...

- *Booster 15 Hz upgrades*
- *Linac/Booster reliability*
- *New g-2 Experiment*
- *Run II extension / Run III*
- *Efforts on MicroBooNE, ANU, LBNE, NML, SRF, etc.*